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# THz frequency, Goniometric scanning system for human cornea using off-axis parabolic mirrors

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***Abstract*—An efficient method for rapid, non-contact scanning of human cornea is presented. The optics utilize two, 101.6-mm diameter off-axis parabolic mirrors fed by a goniometrically scanned, planar mirror. An evaluation system at 650 GHz was built and demonstrated ~ 1.5 mm beam radius on target and ~ 30º x 30º field of view. The system was inspired by confocal laser scanning principles and represents a system design where image acquisition time is limited by SNR, not mechanical translation.**

## I. INTRODUCTION

CORNEAL imaging with THz radiation is typically a slow process involving the rectilinear/planar translation of mirrors, the THz transceiver, or the target itself [1, 2]. While many applications rely on measurements from the central cornea, there are many use cases that necessitate spatially resolved reflectivity measurements across a sizable solid angle *in vivo*. Achieving *in-vivo* imaging is difficult as (1) the eye of a non-anesthetized patient/animal is under continuous, involuntary movement and (2) the tear film thickness changes dynamically between each blink response. Potential solutions to these challenges include concomitant eye tracking feeding real-time, post-acquisition signal adjustments to address misalignment sensitive transceiver coupling and adjunct methods to independently quantify tear-film properties.

Motion artifacts and time-varying properties are also a major source of error in standard ophthalmologic imaging systems. These are often addressed by increasing data-acquisition speed and image display creating a stream of images where the dynamics within each frame is minimized. This work was inspired by real-time optical imaging system layouts and builds on earlier work that utilized slow rectilinear scanning [3].

## II. RESULTS

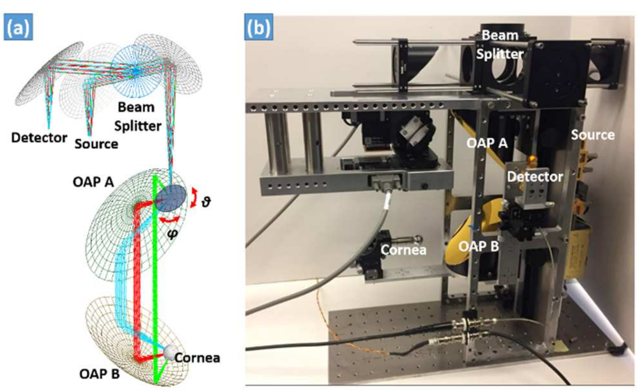


**Fig. 1.** (a) ray tracing system showing transceiver OAPs and the scan OAPs labeled OAP A and OAP B. (b) Constructed prototype.

A layout of the system is shown in Figure 1(a) and the constructed system is in Figure 1(b). A 650 GHz, amplified multiplier chain coupled to a diagonal feedhorn (G = 23 dB) is collimated by a 50.8-mm CA, 101.6 EFL OAP and then focused with an identical OAP to a planar scan mirror. The scan mirror feeds the focal aperture of a 101.6-mm CA, 101.6-mm EFL OAP (OAP A) with a diverging beam. The planar mirror scans over θ and φ which results in an equiangular scan over the cornea with a converging beam emanating from OAP B. The scattered beam is rerouted to the WR-1.5 zero-bias Schottky diode detector via a beam splitter which optically collocates source and detector. OAP mirrors A and B are identical and arranged as a mirror images resulting a π - θ relationship between mirror angle θ and pixel location π - θ. The useable FOV is ~ 30 °× 30 °about the corneal apex.

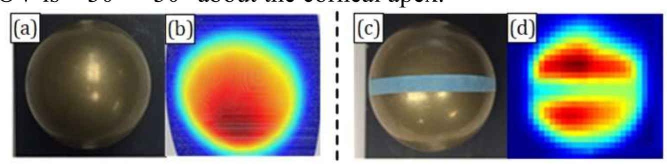


**Fig. 2.** Imaging results (a) 9.525-mm radius of curvature brass sphere. (b) THz reflectivity image. (c) brass sphere from (a) with a 2-mm wide tape strip applied. (d) THz reflectivity image of (c).

A reflection map of a brass sphere (Figure 2(a)) is shown in Figure 2(b) and shows good uniformity across the field of view. A 2-mm thin strip was applied to the surface of the same brass sphere (Figure 2(c)) and an image was acquired in as shown in Figure 2(d). The two-pass absorption from the tape adhesive is clearly seen.

## III. SUMMARY

A THz imaging system that generates non-contact images of spherical targets was presented. The system works in the same manner as a laser scanning microscope where a goniometric stage sweeps a diverging beam at the back focal point of an objective producing a spherical scan of a focused beam about the objective focal point. Here the objective was a pair of low f/# OAPs. The results demonstrate a path towards SNR limited, THz scanning of cornea.

## REFERENCES

[1] A. S. Virk, Z. B. Harris, and M. H. Arbab, "Development of a terahertz time-domain scanner for topographic imaging of spherical targets," *Optics Letters,* vol. 46, pp. 1065-1068, 2021/03/01 2021.

[2] Z. D. Taylor, J. Garritano, S. Shijun, N. Bajwa, D. B. Bennett, B. Nowroozi, P. Tewari, J. W. Sayre, J. P. Hubschman, S. X. Deng, E. R. Brown, and W. S. Grundfest, "THz and mm-Wave Sensing of Corneal Tissue Water Content: In Vivo Sensing and Imaging Results," *Terahertz Science and Technology, IEEE Transactions on,* vol. 5, pp. 184-196, 2015.

[3] S. Sung, S. Selvin, N. Bajwa, S. Chantra, B. Nowroozi, J. Garritano, J. Goell, A. Li, S. X. Deng, E. Brown, W. S. Grundfest, and Z. D. Taylor, "THz imaging system for in vivo human cornea," *Terahertz Science and Technology, IEEE Transactions on,* vol. 7, 2017.