Broadband Polarimetric Imaging Microscope for Cancer Imaging

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Abstract: We report a broadband reflection-mode Mueller-Matrix microscope enabling fast full-Stokes imaging of melanoma and breast tissue. The system reveals polarization signatures that distinguish healthy and cancerous regions, demonstrating strong potential for early cancer detection and margin assessment.

1. Introduction

Distinguishing cancerous tissue from healthy regions remains a major challenge for in-situ detection in dermatology and breast surgery. Biopsy with histopathology is accurate but invasive and slow, while Optical Coherence Tomography (OCT) [1] and Reflectance Confocal Microscopy (RCM) [2,3] offer useful optical contrast yet are limited in resolution, penetration depth, or field-of-view. These constraints motivate development of a quantitative, label-free method for rapid and objective cancer assessment. Mueller-Matrix Microscopy (MMM) measures how tissue alters polarized light, enabling extraction of birefringence, depolarization, and anisotropy parameters that are highly sensitive to pathological changes. Such polarization biomarkers can reveal information associated with malignancies. Here, we present a broadband reflection-mode MMM system with full-Stokes capability across visible wavelengths. Using a polarization-sensitive Complementary Metal-Oxide-Semiconductor (CMOS) camera, motorized Polarization State Generator (PSG), and programmable wavelength control, the system enables fast Mueller-matrix acquisition. We demonstrate label-free contrast for melanoma and breast cancer characterization, highlighting its potential for clinically translatable optical diagnostics.

2. Results and Discussion

The broadband reflection-mode MMM system integrates a polarization-sensitive CMOS camera (Lucid Triton TRI050S-PC) and a QWP as the PSA, a motorized QWP and linear polarizer as the PSG, and a programmable filter wheel for wavelength selection from 500–700 nm. This configuration enables rapid full-Stokes acquisition and accurate Mueller-matrix reconstruction with minimal mechanical overhead. Calibration with a reference mirror produced stable instrument matrices across the spectrum, allowing reliable extraction of retardance and depolarization. The system provides ×4 to ×14 magnification with micrometer-scale resolution, up to 30 fps frame rate, and Stokes parameter errors <5% (standard deviation <2%). Fig. 1 shows the setup schematics.

Using this system, fresh breast tissue was first evaluated. As shown in Fig. 2, linear retardance and MMT-β maps revealed strong contrast between healthy glands and cancerous regions: healthy tissue exhibited organized, less glands, whereas malignant areas showed disrupted structure and more glandular cells. These features were not visible in intensity images, demonstrating complementary diagnostic value for margin assessment.

We next characterized paraffin-embedded melanoma without sectioning. Total retardance and depolarization maps delineated tumor boundaries and stromal heterogeneity with clear wavelength dependence. Fig. 3a and 3b show the melanoma sample's visible image and pathological scan. Fig. 3c shows the 700-nm depolarization map, highlighting stronger depolarization in melanoma than in surrounding dermis or fat. Fig. 3d presents the circular retardance image, revealing distinct tumor-associated polarization rotation. Fig. 3e shows the total retardance distribution, emphasizing transitions among melanoma and collagen-rich dermis. Based on these MMM parameters, a neural-network model generated a segmentation map (Fig. 3f) that accurately classified melanoma, fat, and dermis, with Fig. 3g showing

strong agreement when overlaid on the raw mono image. The digital pathology reference (Fig. 3h) confirmed the predicted tissue distribution, with only minor fat inclusions inside the melanoma region not captured by the model.

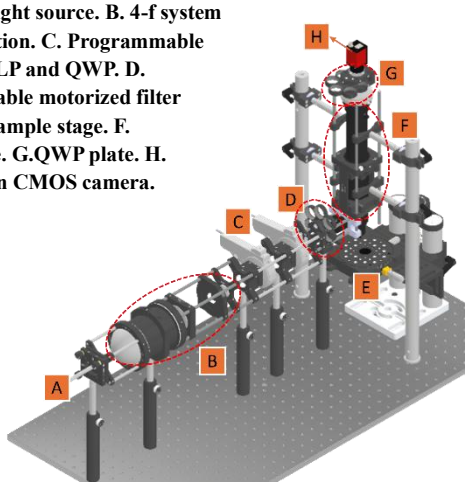

Fig.1 Schematics of the MMM setup. A. Light source. B. 4-f system for collimation. C. Programmable motorized LP and QWP. D. Programmable motorized filter wheel. E. Sample stage. F. Microscope. G.QWP plate. H. Polarization CMOS camera.

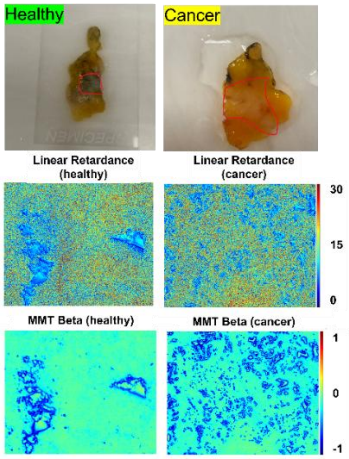

Fig.2 **Comparison of linear retardance and MMT-beta between healthy and cancerous fresh breast samples.**

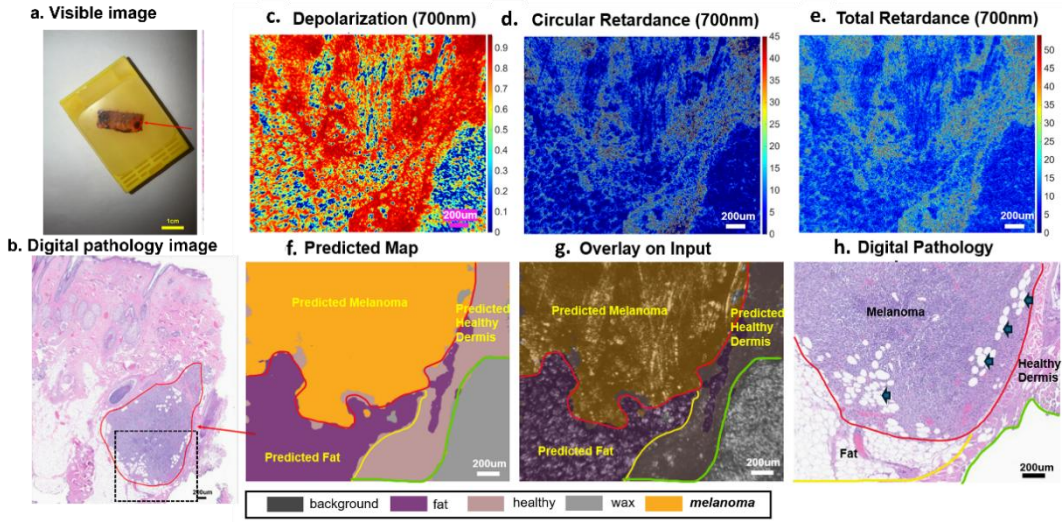

Fig.3 **Melanoma sample, polarization and digital pathology images, and neural network-based segmentation.**

3. Conclusion

In summary, we have demonstrated a broadband reflection-mode Mueller-Matrix microscope capable of fast, label-free polarimetric imaging for both breast cancer and melanoma detection. Future work will expand tissue studies and advance real-time analysis to establish a cost-effective, clinically translatable method for early-stage cancer detection.

References

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