Early Characterization of Melanocytic Lesions Through Dynamic Thermography and Multispectral Imaging

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***Abstract*—Early and accurate differentiation of benign, dysplastic, and malignant skin lesions is critical for effective melanoma screening. This paper evaluates the effectiveness of the MelanoDet system in distinguishing three clinically significant skin lesion types: benign nevus, dysplastic nevus, and melanoma. Using three detailed case studies, we analyze the unique morphological and thermal characteristics of each lesion through multispectral imaging, combining visible (VIS), near-infrared (NIR), and thermal (TH) modalities. Static imaging captures structural and subsurface features, while dynamic thermography assesses physiological response following a cooling stimulus. The results demonstrate MelanoDet's potential as a non-invasive diagnostic tool for early detection and accurate analysis of melanoma, contributing to improved patient outcomes.**

***Index Terms*—Multispectral Imaging, Melanocytic Lesions, Thermography, Melanoma Detection, Non-Invasive Diagnostics**

I. INTRODUCTION

Melanoma is an aggressive form of skin cancer arising from melanocytes and accounts for the highest mortality among skin cancers, despite being highly curable when diagnosed early [1], [2]. Dermoscopy, a widely used non-invasive diagnostic tool, achieves approximately 90% accuracy [3]; however, up to 10% of cases may still be misdiagnosed, necessitating histopathological confirmation. As a precaution, dermatologists often excise lesions with even minor atypical features, which, while reducing the risk of missing melanoma, may lead to unnecessary surgical procedures.

To address these diagnostic limitations, there is growing interest in non-invasive imaging technologies that can improve lesion characterization. Among them, multispectral imaging (MSI) and thermal imaging (THI) have shown great promise. MSI captures structural and subsurface features across various spectral ranges (visible (VIS) and near-infrared (NIR)), while THI uses long-wave infrared (LWIR) to assess temperature-related physiological responses [4], [5].

Recent studies have made significant progress in developing MSI and THI systems specifically for skin cancer assessment. Various MSI systems have been designed using different types of cameras, wavelength ranges, and illumination methods to improve skin lesion analysis. Early MSI devices featured monochromatic CCD cameras combined with LED rings that emit light at wavelengths from 350 to 995 nm [6], [7]. More advanced setups have integrated NIR cameras with multiple LED arrays to capture a wider spectral range of 414 to 1613 nm, allowing deeper tissue visualization [8]. For example, the Barco® Demetra multispectral dermoscope acquires images between 400 and 800 nm to improve visualization of the skin structures beneath the surface [9].

To further improve image contrast, some MSI systems include polarization techniques, using dual polarizers and multispectral illumination in the VIS and NIR ranges [10]. Another approach involves mosaic cameras equipped with Fabry–Perot interference filters on CMOS sensors, which produce images at specific wavelengths for detailed lesion characterization [11], [12].

Alongside MSI, THI has been employed to study the thermal properties of melanoma. Systems combining LWIR and RGB cameras allow dynamic temperature monitoring and early detection through thermal recovery analysis [13], [14]. One notable prototype, HypIRskin, incorporates a long-wave infrared camera alongside an RGB camera with polarizing filters and other components, enhancing thermographic diagnosis of skin lesions [15].

While MSI and THI have shown diagnostic potential individually, no current system has integrated both. To fill this gap, we developed MelanoDet [16], a hybrid system combining static MSI for morphological analysis with dynamic THI to assess thermal response. Thus, this study evaluates MelanoDet's ability to differentiate benign nevus, dysplastic nevus, and melanoma. Through three representative case studies, we analyze distinct morphological and thermal features, demonstrating the system's potential as a non-invasive tool for early and accurate lesion classification.

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II. Data Acquisition

A. Acquisition System

The experimental setup, illustrated in Fig. 1 and originally presented in [16], includes three co-mounted cameras: VIS, NIR, and THI. The VIS module consists of a USB 3.0 camera with a Sony CMOS sensor, equipped with a 5 MP RGB Marshall varifocal lens. For NIR imaging, a 10-bit Blackfly® S FLIR camera with a 5 MP Sony CMOS sensor is used, paired with a Fujinon C-Mount lens. NIR imaging is supported by a 940 nm LED box to reveal subsurface structures like veins. Lastly, the TH camera, Optris PI 450, detects temperature differences as small as 0.04 K and operates in the 8–14 µm spectral range.

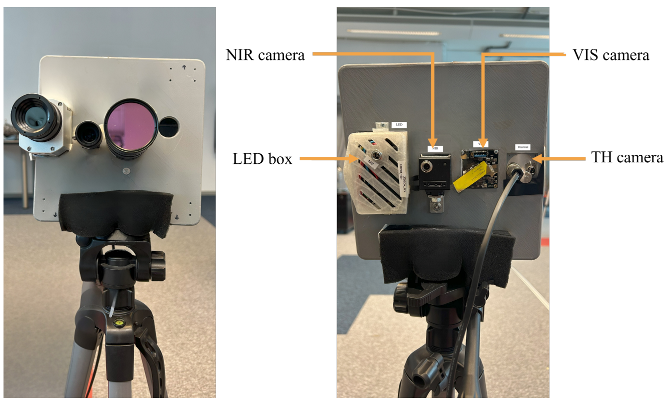

Fig. 1: MelanoDet System.

B. Acquisition Protocol

The image acquisition protocol was standardized in collaboration with a dermatologist to ensure consistency and reliability. Subjects were positioned 40 cm from the camera system, with a non-reflective square marker used to define and center the region of interest (ROI) for precise anatomical alignment across sessions. To minimize motion artifacts, participants were instructed to remain still during imaging. Data collection was divided into two phases: a static phase capturing VIS, NIR, and LWIR images for structural and thermal analysis, followed by a dynamic phase where a cooling stimulus was applied to the lesion, and a 3-minute video was recorded.

C. Dataset

The dataset follows the established imaging protocol. A total of 88 cases were collected, with diagnoses established either by dermatologists or through histopathological analysis. Cases were classified as benign nevus (NV), dysplastic nevus (DN), or melanoma (MM). All participants provided informed consent, and the study was conducted in accordance with the Declaration of Helsinki. For each case, three static images and a dynamic thermal video of approximately three minutes were obtained.

III. Case Studies

To demonstrate the capabilities of MelanoDet, three confirmed cases (one each NV, DN, and NV) were analyzed using VIS, NIR, and LWIR modalities. The aim was to evaluate how combined structural and functional imaging can aid in identifying features specific to atypical and malignant lesions.

A. Static Phase

The images acquired in the static phase for the three classes are depicted in Fig. 2. For each case the image triad is presented in the following order: VIS image, NIR image and TH image.

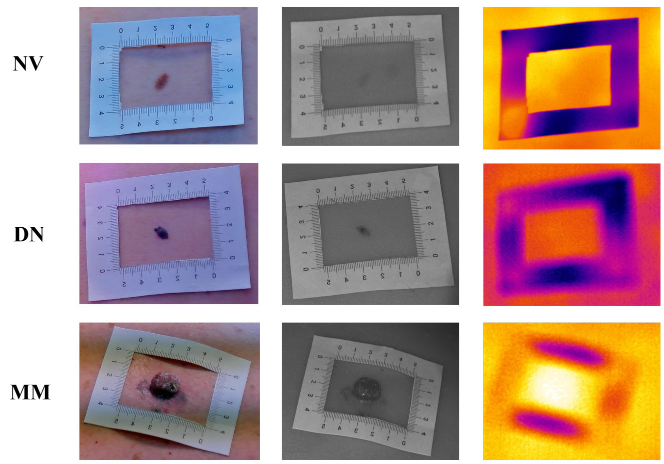

Fig. 2: Example of images acquired for the three classes: NV, DN and MM.

The first row depicts an NV lesion, with the VIS image showing a regular, oval shape, well-defined borders, and uniform pigmentation, characteristics typical of benign nevi. The NIR image reveals low contrast between the lesion and the surrounding healthy skin, suggesting limited depth and a minimal vascular network. The TH image shows no significant temperature variation at the lesion site. This absence of elevated thermal activity implies a lack of increased metabolic or vascular activity, further supporting the benign nature of the lesion.

For the DN case, the VIS image reveals a pigmented lesion with asymmetry, irregular borders, and coloration ranging from light brown to dark brown and black. These morphological characteristics are associated with atypical nevi, which are considered intermediate-risk lesions with potential for malignant transformation. The NIR image reveals increased contrast in specific regions, indicating deeper pigmentation layers that correspond to deeper structures below the skin surface. In contrast, in the TH image, the lesion is not distinguishable from the surrounding skin, and there is no notable temperature elevation, consistent with low biological activity when compared to melanoma.

Regarding MM, the VIS image presents a lesion with asymmetry, irregular borders, and heterogeneous pigmentation. Additionally, the lesion appears elevated, with peripheral pigmentation extending into the surrounding skin, indicative of radial growth and potential dermal invasion. The NIR image reveals enhanced subsurface visualization, and the lesion displays greater contrast compared to the surrounding tissue, which may correspond to increased vascular density. The TH image presents a significant temperature elevation at the lesion site, forming a high-temperature core compared to surrounding tissues, which is indicative of increased metabolic activity.

B. Dynamic Phase

For the dynamic phase, Fig. 3 shows representative frames from the 3-minute video acquired, illustrating the thermoregulation process of the tissues. This process can differentiate between healthy and pathological tissue, as malignant lesions typically possess a denser vascular network, causing them to warm more rapidly.

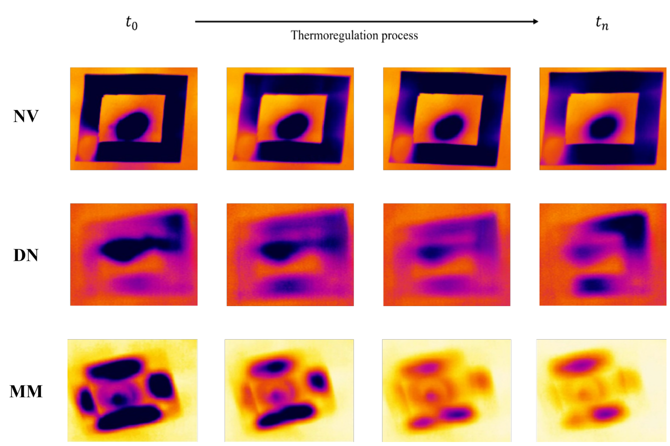

Fig. 3: Example of frames extracted from the thermal videos after applying a cooling stimulus.

The NV sequence shows very stable thermal behavior throughout the observation period. Its temperature remains consistent over time, with only small changes. This steady pattern suggests normal blood flow and metabolism, typical of benign lesions. In contrast, DN shows moderate changes in temperature, representing an intermediate behavior between benign and malignant lesions. Notable changes in the thermal pattern are observed, with some areas reheating, while others remain relatively stable. This behavior reflects the mixed nature of dysplastic nevi; they may have increased metabolic activity or changes in blood flow that distinguish them from simple nevi but have not yet progressed to malignancy. MM displays the most dynamic thermal behavior among the three lesion types, with significant changes in temperature distribution evident across the entire time sequence, likely due to the dense vascular network supplying the lesion. The lesions reheats itself in only 7 seconds, compared to the other two lesions. In the NV case, the lesions did not reheat to the skin temperature in the 3-minute video, while in the DN case, the lesion reheated itself after 1.5 minutes.

IV. Conclusion

This study demonstrates the effectiveness of the MelanoDet system in characterizing pigmented skin lesions using a multispectral imaging approach. In benign nevi, the consistent morphology observed in VIS and NIR images, combined with thermal neutrality in THI, reflects normal vascular and metabolic activity. Dysplastic nevi, by contrast, show moderate thermal variability and less defined structural features, positioning them between benign and malignant profiles. This comparative analysis reveals a clear trend: as malignant potential increases, so does thermal instability and heterogeneity. These findings highlight the value of combining VIS, NIR, and dynamic IRT to capture complementary morphological, subsurface, and physiological information. This approach enhances lesion characterization and improves differentiation between benign, atypical, and malignant skin lesions.

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