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Efficient Descriptor of Histogram of Ridges Orientation Delineate for Fingernail

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Abstract. Orientation, ridges, and edges are prominent features of fingernail structure. This paper proposes a local descriptor based on ridge orientation, called Histogram of Ridges Orientation Delineate (HROD), based on Edge Histogram Descriptor (EHDD). As humans perceive images by looking at edge features, Finger HROD utilizes this sensitivity. Before performing feature extraction, the HROD algorithm conducts a range of pre-processing steps, including resizing, filtering, enhancing, and segmenting images. After this, the ridges orientation delineate maps are obtained by selecting an orientation with the maximum edge magnitude for each pixel based on predefined orientations. This study utilised five oriented edge maps to generate and detect the maximum edge orientations of each block: vertically, horizontally, diagonally at 45°, diagonally at 135°, and isotropically (non-orientation-specific). The results of experiments conducted on fingernail images demonstrate that the performance of HROD is similar to that of advanced orientation-based methods such as the Gabor filter, histogram of oriented gradients, and local directional code. Additionally, the HROD algorithm being suggested offers the benefits of minimal feature complexity and quick execution, making it ideal for a real-time system designed to recognize fingernail orientations.

Keywords: Edge Histogram Descriptor (EHD), Histogram of Ridges Orientation Delineate (HROD), Edge Orientation, Bit-Point (BP), Vertical Edge Orientation, Horizontal Edge Orientation, Diagonal Edge, Non-Edge Orientation (İsotropic).

I. INTRODUCTİON

The nail tissues are a complicated structure found on the surface and edges of the hands (fingertips) and feet (toes). The primary purposes of these nails are to provide protection and a sense of touch. To comprehend the causes of nail diseases and related health issues, it is essential to have a basic knowledge of the anatomy of the nail structure [1]. In general, the nail is made up of the nail matrix, lunula (half-moon-shaped area), nail fold, nail plate, and nail bed [2]. Figure 1 shows the complete structure of a nail.

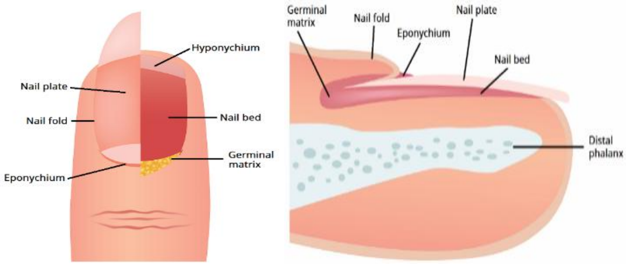

Fig. 1. Illustrated Diagram of Nail Anatomy [3]

The nails reflect the overall health and conditions and could be an obvious sign of a severe case. Therefore, knowledge of the basic structure of nails and the ability to recognise various types of nail colours, lines, and formations enables healthcare professionals, such as general practitioners, clinicians, and hospital staff, to effectively diagnose and treat nail disorders, as well as identify potential underlying systemic illnesses. [1]. The authors of a 2015 study [4] emphasized the significance of nail condition, stating that dermatologists should make it a practice to carefully inspect the nails during each routine visit as even minor abnormalities can be indicative of underlying systemic diseases. As a nail technician, it is common to encounter nails that are fragile and prone to breakage, often characterised by the presence of white spots, lines, or ridges. The white horizontal lines on the nails may be Beau's lines, which show up as horizontal indentations in the nail surfaces [5]. These lines typically indicate underlying problems in the body, such as long-term health issues, injuries, or a response to medication, and could indicate the presence of toxins [6]. It is common for patients (44%) undergoing chemotherapy to experience changes in the colour of their nails [6-8]. Nevertheless, in a population without a past of significant drug-related harm, these lesions could serve as essential indicators in identifying systemic illness [9]. Some patterns and nail lines are visible in figures 2 (A) and (B), while others are less noticeable in figure 2 (C).

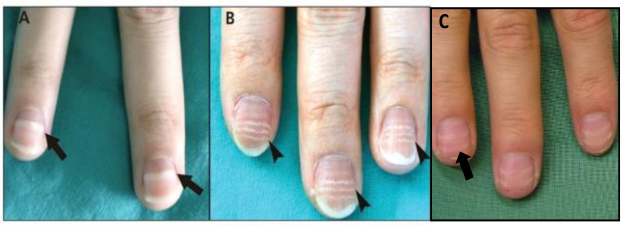

Fig. 2 (A) A 27-Year-Old Woman has Lines (Arrows) in her Fingernails. (B) There are Arrow-Shaped Beau Lines Present on the Fingernails of a 41-Year-Old Woman, and (C) There are Beau Lines Present in the Fingernails of a Man [5]

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Beau lines and onychomadesis can be caused by trauma, s urgery, infection, Raynaud disease, pemphigus, or chemothe rapy (such as toxoids) [6-8].

In contrast, Mees lines (also known as true leukonychia) are characterized by a distinct change in colour of the nail without any lines running from the lunula to the tip of the nail, and without any noticeable ridges [6]. Mees' lines have connections to arsenic poisoning, Hodgkin lymphoma, carcinoid tumours, and certain types of chemotherapy such as cyclophosphamide, vincristine, and doxorubicin. Muehrcke lines can be distinguished from Mees lines by the fact that Muehrcke lines fade when pressure is applied to the nail and do not shift as the nail grows.

Meandering lines (also known as Mees lines) can be linked to arsenic poisoning, Hodgkin lymphoma, carcinoid tumours, and the use of certain chemotherapeutic drugs such as cyclophosphamide, vincristine, and doxorubicin. Muehrcke lines are caused by liver disease, nephrotic syndrome, malnutrition, and severe hypoalbuminemia [6-8]. However, in the case of genuine leukonychia, the white discoloration is not influenced by pressure and instead progresses towards the tip of the nail as it grows, a progression that can be documented through sequential photographs taken during follow-up appointments [10]. Mees' lines are linked to various systemic stresses, including acute renal failure, heart failure, ulcerative colitis, breast cancer, infections like measles and tuberculosis, and diseases such as systemic lupus erythematosus. They can also be caused by exposure to toxic metals like thallium [11]. Another form of white stripes on the nails (Onychomycosis) can also occur as a fungal infection, which is responsible for around 50% of all nail disease cases. This infection can appear as white or yellowish lines running along the nail, accompanied by thickening of the skin around it, known as a dermatophytoma. Figure 3 depicts the white-yellow lines [1].

Fig. 3. Fungal Infection in the Big Toenail Causing A Dermatophytoma, Which Can Be Seen As A White-Yellow Stripe Running Lengthwise [1]

One way to stain subungual debris with potassium hydroxide can be used to look for signs of a fungal infection when examined under direct microscopy [12]. Instead, you can send a piece of nail clipping in a container with 10% buffered formalin and request a fungal stain like periodic acid-Schiff [13]. Under the microscope, a dermatophytoma reveals a concentrated cluster of dermatophyte hyphae, also known as a fungal abscess. The detective's role in diagnosis is crucial, as clinical findings that indicate dermatophytoma are linked to a lack of improvement with antifungal treatment [14]. However, these techniques and observations highly require skilled staff and professional clinical practice, as well as expensive tools and equipment, such as microscopes.

Various health conditions can lead to alterations in the nails and nail bed, such as the formation of ridges on the nails. The most common type of ridges found in fingernails is vertical ridges, and they are typically harmless. This type of ridge on the fingernail is typically a result of getting older. To be more precise, this is due to the ageing of the nail matrix. As the cells in the nail bed deteriorate over time, they produce a fingernail with uneven vertical ridges. Nonetheless, horizontal ridges and lines frequently indicate an underlying health issue that needs to be identified and treated. Therefore, examining the fingernails and toenails, as well as their structure, should be included in both comprehensive physical exams and regular check-ups. As a result, this study offers a straightforward method for monitoring and examining the structure of fingernails, which can enhance and expedite the overall inspection process. Furthermore, the micro-lens on the mobile phone can identify fine lines and small structures that are not visible to the naked eye, allowing for the collection of precise data and the generation of traditional outcomes.

II. METHOD

A. Experimental Setup

The experimental setup was constructed using hardware and image processing techniques (IPT). The Internet of Things (IoT), computer vision, and artificial intelligence (AI) have enabled manufacturers and researchers to automate a wide range of tasks. This study has made a special effort to develop complex technology that is robust and mature, meeting the high demands of modern general clinical practice. The method is easier to apply in our system, as it simply utilises a low-cost consumer micro-lens attached to the phone to capture high-resolution images of nails and to quantify symptoms that may affect the nails themselves, thereby developing an automated nail monitoring system for potential illness detection. Figure 4 shows the experimental setup. The system includes a micro-lens, a phone, an adjustable phone handle, a USB cable, a piece of clothing or paper (for background enhancement), and a MATLAB algorithm script.

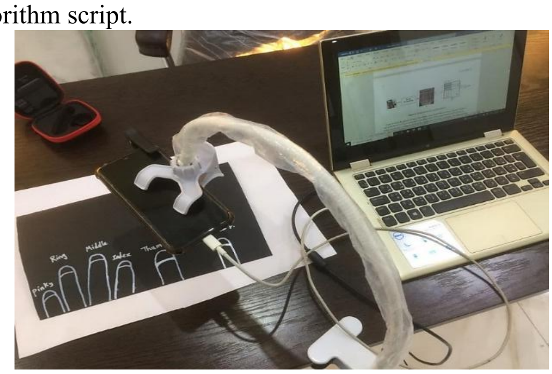

Fig. 4. The Overall System Design and Experimental Setup

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B. Examining Algorithm

Image pre-processing techniques are primarily utilized to enhance obscured details or emphasize specific features of interest in an image. These are mainly procedures designed to leverage an image search and capitalise on the human visual system's strengths. The Content-Based Image Retrieval (CBIR) and Histogram of Ridges Orientation Delineation (HROD) equalisation techniques were used in conjunction with the proposed method algorithm to enhance detection.

The CBIR is also known as query by image content, which refers to the process of retrieving an expected image from an image database according to the content of the query image. The image's content primarily consists of its colour, texture, and shape characteristics, which can be automatically extracted from the image through various feature extraction techniques.

The CBIR differs from traditional methods that rely solely on metadata, such as keywords, tags, or descriptions, which are linked to the image. The keyword in the conventional technique also limits the scope of queries because of the predetermined criteria. At the same time, the CBIR technique offers the flexibility to search and focus on the content of the image without predefined criteria. Figure 5 shows the CBIR technique that was implemented in this study.

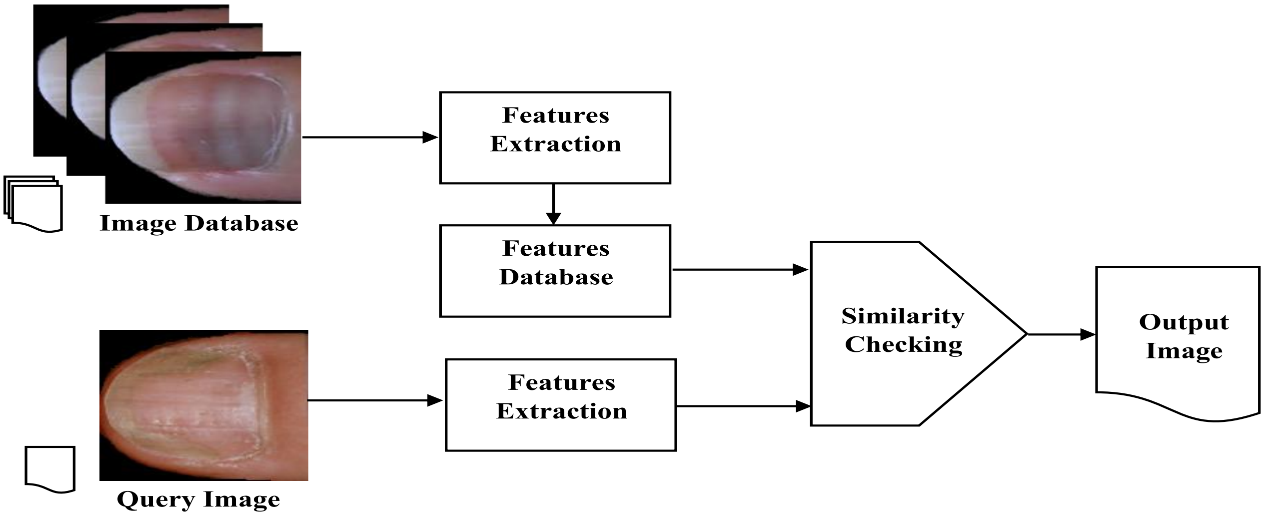

Fig. 5. The CBIR Technique Algorithm

Figure 5 illustrates the overall extraction process of finding the closest match between the query image and images in the database, based on the minimal distance features between these images. Based on the minimum and smallest distance, the features can be extracted easily; thus, the output can be obtained with the most similar features. More details will be explained in the following section.

C. Algorithm Data Processing

Many descriptor methods can be used to extract the interesting features, similarities, and differences of images, such as colour, texture, shape, motion descriptors, and localisation. In this study, the edge histogram descriptor (EHD) is utilised as a type of texture descriptor. The EDH is a strong descriptor used for image search and retrieval at a basic level. Therefore, the arrangement of edges serves as an effective texture signature utilised in the process of matching images. The use of the EDH is beneficial when the underlying area has non-uniform texture properties. The EDH represents the spatial distortion of edges, which can be classified into five main categories: vertical, horizontal, diagonal at 45 degrees, diagonal at 135 degrees, and isotropic (not specific to orientation). Figure 6 displays the intricate block diagram of the proposed methodology.

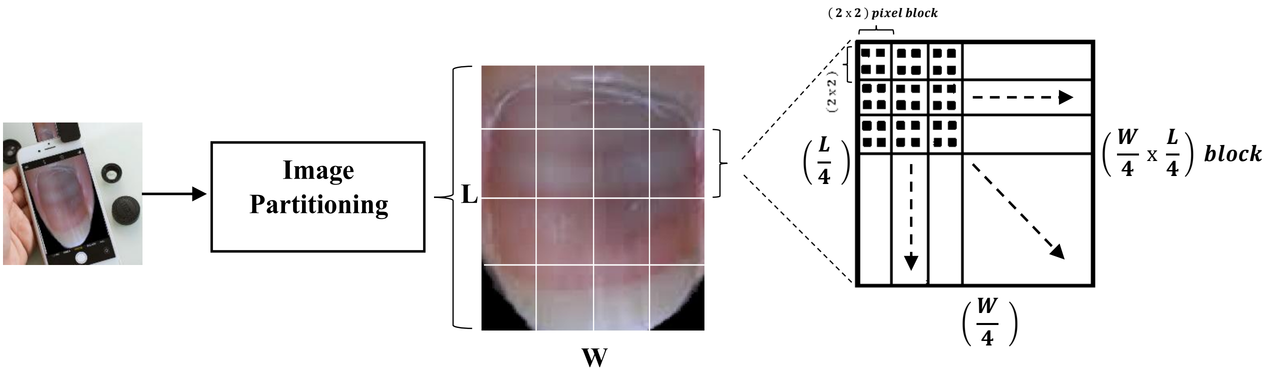

Fig. 6. Image Partitioning Implementation

Figure 6 shows the process of image partitioning which divided the raw image into the length *(L)* and width *(W)* of *4×4* (*16* sections) non-overlapping block. Each extracted block of *16* sections is further divided into a *2×2* small pixel block for capturing the local edge orientation. The capturing edge orientation for each extracted block $\left(\frac{W}{4} \text{ x } \frac{L}{4}\right)$ (1) is then initialized by *5* Bit-Point (*5BP*) as following; *BP = [V, H, D45, D135, NON] = [0, 0, 0, 0, 0]* (2)

Where *BP* is Bit-Point*, V* represents Vertical edge orientation, *H* is Horizontal edge orientation, *D45* is Diagonal edge at *45°* orientation, *D135* is Diagonal edge at *135°* orientation, and *NON* is non-edge orientation (isotropic).

Therefore, the partition image has *16-BP[N]* for all *16* blocks, as an overall total, and each of these blocks comprises 5-BP. Thus, if the BPs are kept side by side, they form an EHD vector of a total length of 80 bp.

$$EHD = \begin{pmatrix} BP[1] & BP[2] & BP[3] & BP[4] \\ BP[5] & BP[6] & BP[7] & \boxed{BP[8]} \\ BP[9] & BP[10] & BP[11] & BP[12] \\ BP[13] & BP[14] & BP[15] & BP[16] \end{pmatrix} \rightarrow [V, H, D45, D135, NON] \quad (3)$$

To capture the local edge orientation from each 2×2-pixel subblock, an operator of 2×2 will be applied, as shown in Table 1.

Table 1. Five types of Edges in EHD

Edge Type	Visual Representation	Operator Mask
Vertical edge (*V*)		$\begin{bmatrix} 1 & -1 \\ 1 & -1 \end{bmatrix}$
Horizontal edge (*H*)		$\begin{bmatrix} 1 & 1 \\ -1 & -1 \end{bmatrix}$
Diagonal edge (*45°*)		$\begin{bmatrix} \sqrt{2} & 0 \\ 0 & -\sqrt{2} \end{bmatrix}$
Diagonal edge (*135°*)		$\begin{bmatrix} 0 & \sqrt{2} \\ -\sqrt{2} & 0 \end{bmatrix}$
Non-edge orientation		$\begin{bmatrix} 2 & -2 \\ -2 & 2 \end{bmatrix}$

Each operator mask is applied on *2×2* sub block by the following formula;

$$ET = \left|\sum_{i=0}^{3} p_i \cdot m_i\right| \quad (4)$$

Where *ET* represents the Edge Type;

$p_i = \begin{bmatrix} p_0 & p_1 \\ p_2 & p_3 \end{bmatrix}$ represents *2×2*-pixel sub block;

$m_i = \begin{bmatrix} m_0 & m_1 \\ m_2 & m_3 \end{bmatrix}$ represents *2×2* operator mask.

After applying all operators' masks to a single 2x2 image sub-block, the five corresponding edge types (ETs) will be obtained, such as ETv, ETh, ET45, ET135, and ET_{non}. The maximum of these values is compared with a threshold value (*T*) to fin the dominant edge type as following;

$ET_{dominant} = max(ET_v, ET_h, ET_{45}, ET_{135}, ET_{non}) > T$ (5)

After finding the maximum value among these values, the dominant edge type ($ET_{dominant}$) will be equal to that maximum number. Next, the Bit-Point (BP) count corresponding to each 2x2 sub-block is raised by one, and this process is repeated for all sub-blocks within the larger block.

One$\left(\frac{W}{4} \text{ x } \frac{L}{4}\right)$ Image block.

Thus, for one $\left(\frac{W}{4} \text{ x } \frac{L}{4}\right)$ Image block, we obtained the complete Bit-Point *BP* and can be expressed as following;

$BP[1] = [b_0, b_1, b_2, b_3, b_4]$ (6)

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The operations are repeated for all sixteen- $\left(\frac{W}{4} \times \frac{L}{4}\right)$ image block to acquire all *16 BP*. After getting *BP* for all sixteen$\left(\frac{W}{4} \times \frac{L}{4}\right)$ -image block, these *16 BP* can be re-arranging as following;

$$All_{BP} = \begin{pmatrix} b_0 & b_1 & b_2 & b_3 & b_4 \\ b_5 & b_6 & b_7 & b_8 & b_9 \\ . & . & . & . & . \\ . & . & . & . & . \\ b_{75} & b_{76} & b_{77} & b_{78} & b_{79} \end{pmatrix} \begin{matrix} \rightarrow BP\,[1] \\ BP\,[2] \rightarrow \\ . \\ \rightarrow BP\,[16] \end{matrix} \quad (7)$$

For an accurate result, the global BPg can be calculated by taking the mean of each column and then combining all extracted BP values with the global BPg to form the *EHD* vector of *85 PB* in total.

$$EHD = [\underbrace{BP\,[1],\ BP\,[2],\ BP\,[3], \ldots\ldots BP\,[16]}_{80\text{-}BP},\ \underbrace{BP_g}_{5\text{-}BP}] \quad (8)$$

D. Nail Examination Essentials (Protocol)

A complete examination includes all 10 nails (individually or in units) of the hand. Subjects should be instructed to remove all nail polish or any barrier on their nails before carrying out the examination. Photo shoots and careful measurement help document the status of the nails, as well as the overall health condition that might be detected. A set of images in the database is stored for further processing, comparison, and similarity detection. This examination and processing are executed using the MATLAB image processing toolbox, which includes functions such as image acquisition, background subtraction, segmentation, edge detection, filtering, enhancement, feature extraction, normalisation, and classification. In addition, the main CBIR and EHD proposed method was implemented to achieve accurate extraction results. In this examination, a total of twenty (20) participants were involved in the experimental protocol with approval of the Taif University Ethics Committee (No. 44-283).

The committee for Bioethics with No. (HAO-02-T-105) and the committee considered that the proposal fulfils the requirements of Taif University; accordingly, ethical approval was granted (from March 23rd). The participants are asked to place their hand and/or fingertip in the defined position, as shown in Figure 7. However, taking a photo of the whole unit (hand) requires more time and processing, such as resizing, disregarding the palm and fingers, and detecting the area of interest (nails). Thus, this study only considers taking an individual finger at a time.

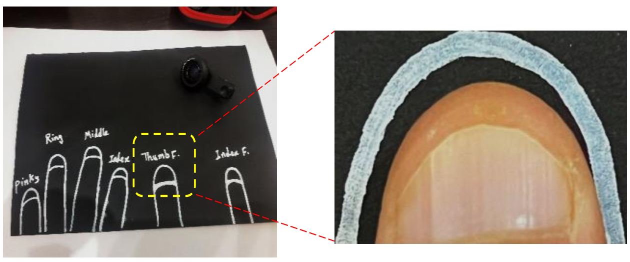


Fig. 7. (a). The Area of Interest (nails), (b). The Nail on Place

In addition, two photos are taken in a row for the same finger where the user asks to place his/her finger with no pushing down toward the table as a first shoot (normal placing), and the second photo is taken with a bit of pressure applied toward the table as shown in Figure 8. The idea is to track all possible fine lines that could appear. However, on occasion, we cannot tell the difference with the naked eye, but by pre-processing and algorithm implementation.

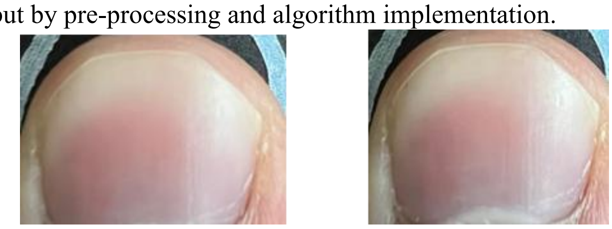


Fig. 8. Capture Two Photos, (a) with no Press, (b) with a Little Push Toward the Table

III. RESULTS AND DİSCUSSİON

A. Analyzing Detection Data

Initial signal processing of the recorded data was conducted using MATLAB software (The MathWorks, Inc., Natick, MA, USA) to assess the effectiveness of the suggested algorithm, alongside a visual examination. Figure 9 shows the nails of different participants that were captured during the examinations.

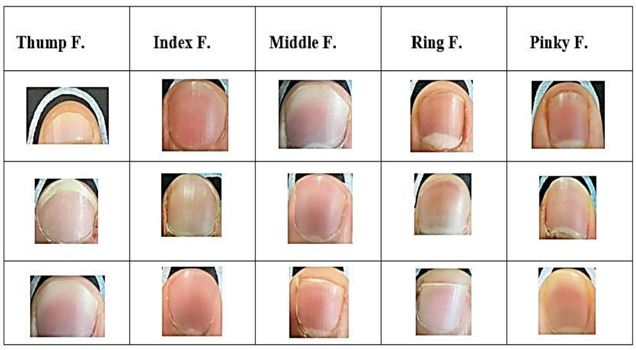


Fig. 9. Fingers (Nails) of Different Subjects

The edge histogram descriptor (EHD) can be easily extracted by implementing the algorithm and compared with database photos for further inspection.

The algorithm operates by analysing each sample and recording the local edge orientation to determine whether the samples are similar to or match the photos in the database. The point where the edge is found is identified by locating the smallest value within a 2x2 pixel sub-block using a 2x2 operator mask.

The running algorithm on the sample detects the maximum magnitude values in each sub-block and scans through the entire target (nail photo) to compare them. Figure 10 shows the outcome of pre-processing and enhancing the data; the time of processing is small, < 7s. The outcomes from the initial detection processing of maximum orientation values are better than those from a physical inspection method. They are not comparable due to the presence of fine lines that cannot be detected with the naked eye.

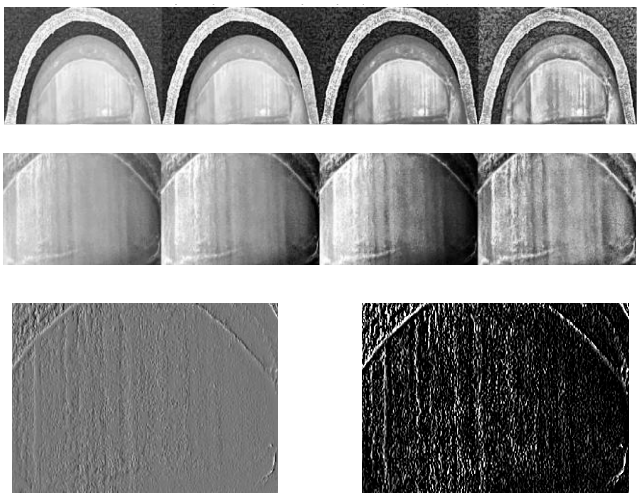


Fig. 10. Outcome Pre-Processing and Enhancement

Figure 11 shows the graph of EHD for both images, comparing the factors that differentiate them from each other.

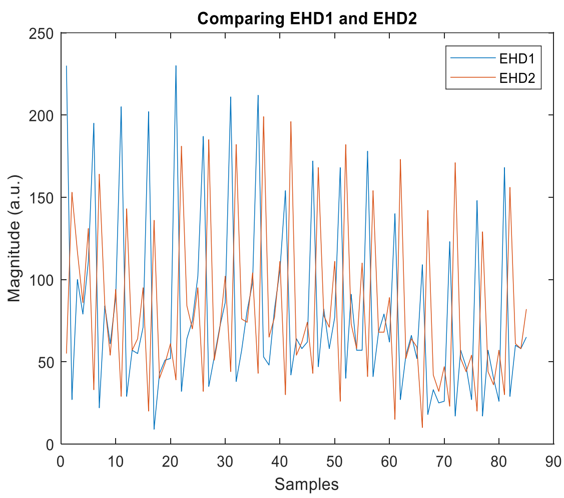


Fig. 11. Comparing of EHD1 and EHD2

Figure 12 shows the global bin of both images. Each bar represents edge orientation, the first bar from the left is vertical, then horizontal, diagonal 45°, diagonal 135° and isotropic (non-orientation specific) at bar number 5.

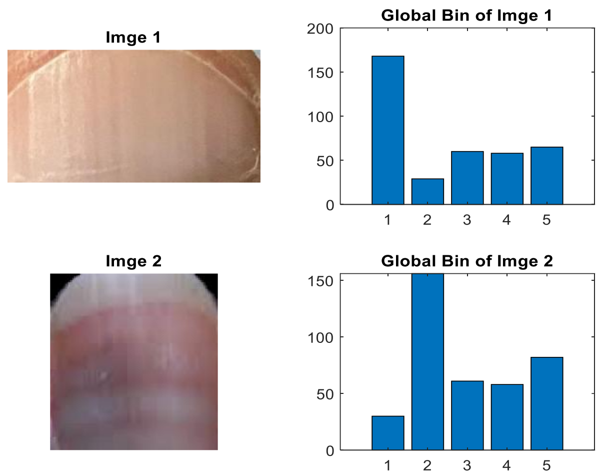
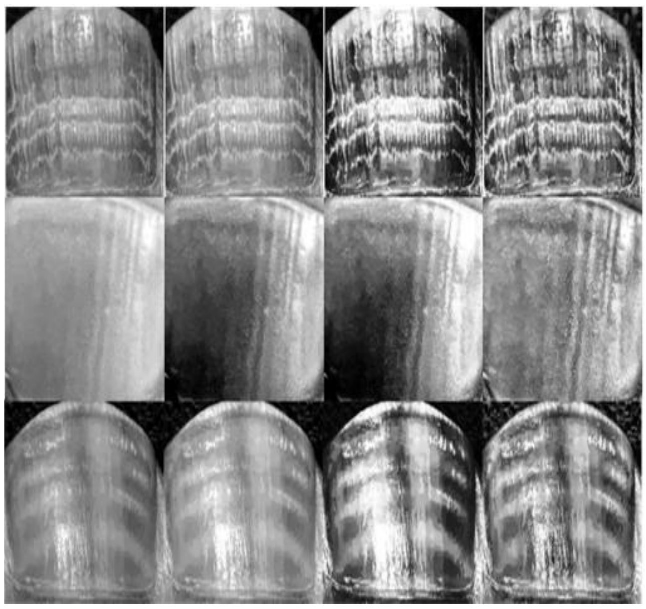


Fig. 12. Edge Orientation Detection of Different Images

It can be seen from Figure 12 that the dominant edge value of the first image is the vertical orientation, representing the maximum number of vertical edges. Similarly, the highest value orientation is represented by a horizontal bin in the second image.

It can also be seen that both graphs have smaller values for other orientations. Occasionally, it is difficult to tell from the image itself with the naked eye. Still, by implementing the Edge Histogram Descriptor (EHD) algorithm, the outcome is obvious and clear on the graph.

Figure 13 shows the comparison that has been taken between the same image. It can be seen that the graphs in Figure 13(b) are identical, as they use the same image for comparison. Both EHD1 and EHD2 match; thus, the blue line legend (EHD1) does not appear in the graph, as it is located exactly underneath the red line (EHD2).



(a)

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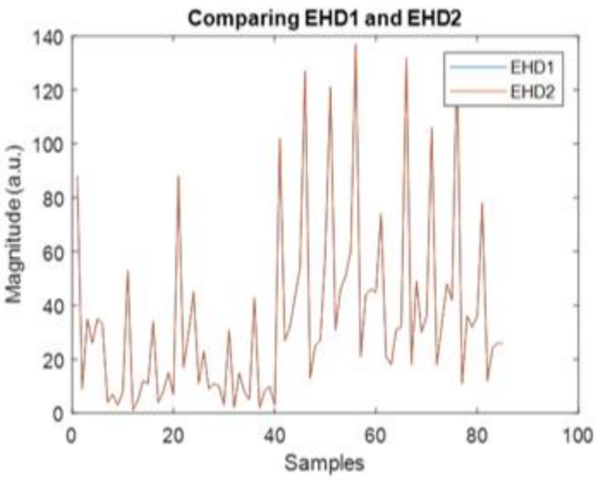

(b)

Fig.13. (a) Enhancement Images, (b) Comparison of Edge Histogram Descriptor

Figure 14 shows the dominant edge orientation of each image. Figure 14 (a) and (b) have the highest horizontal values of bin orientation, while the dominant values in Figure 14 (c) are vertical bins.

The idea of comparing two identical images is to prove the concept of an algorithm and its implementation.

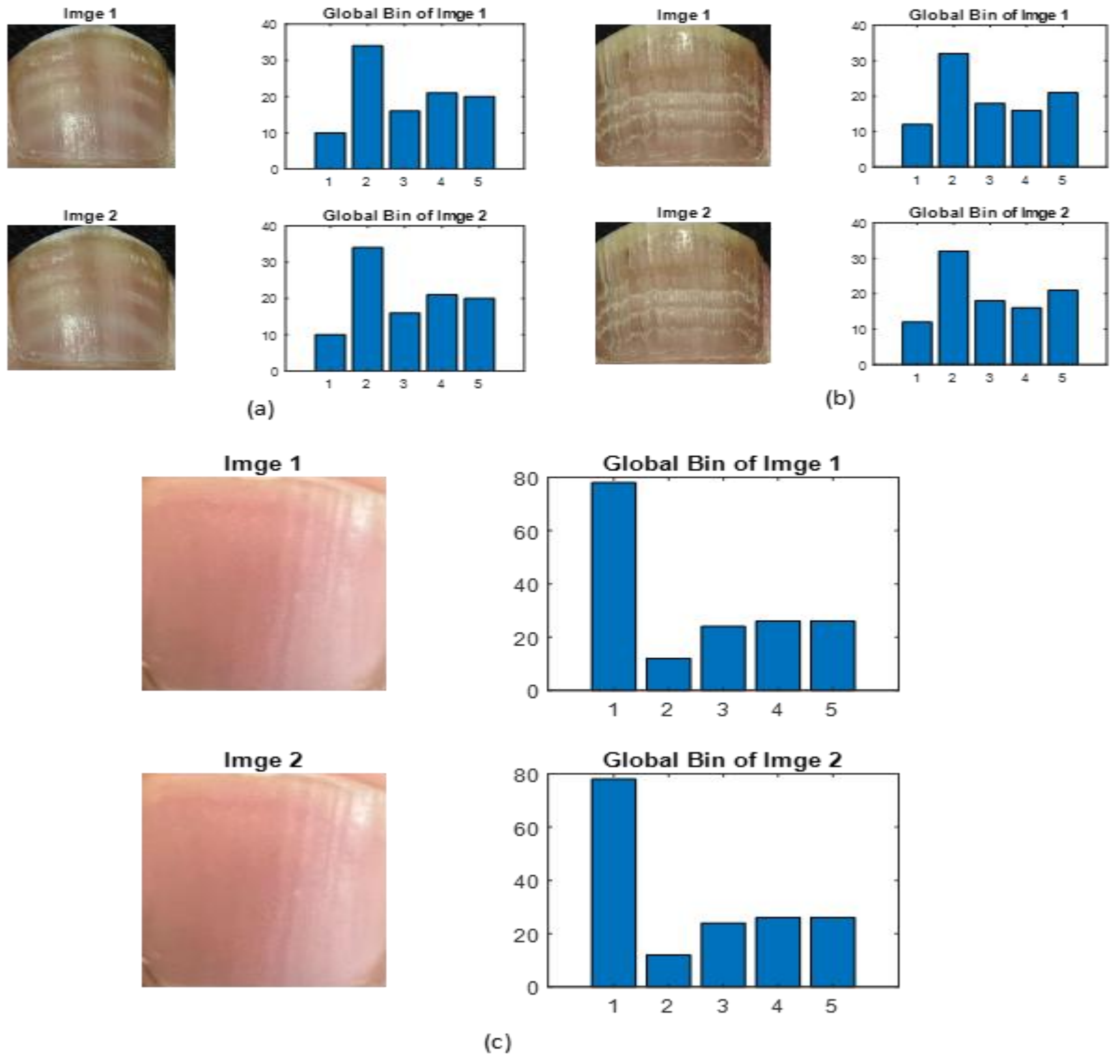

Fig.14. Edge Orientation Detection of Similar Images

IV. CONCLUSİONS

This work introduced a descriptor method, aided by a phone, for capturing the data. The edge histogram descriptor (EHD) is used in this study as one type of texture descriptor of the target (nail). A micro-lens is also used to enhance the quality of the photo and make the texture even more visible. The proposed algorithm is a low-level descriptor for image search and retrieval, providing a good level of agreement and comparability with database images.

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Thus, the distribution of edges is used to investigate the texture signature used for image matching. The EDH is useful when the underlying region is not homogenous in texture properties. The capture of spatial disruption at edges, grouped into different categories (vertical and horizontal), determines the orientation in a small region, resulting in an accurate overall result.

Nevertheless, specific invalid data errors may occur as a result of finger misalignment. This issue can be resolved by ensuring the finger is positioned correctly, adjusting the holder height, and using the phone's zoom functions when capturing data. Moreover, the scarcity of photos in the database could lead to decreased agreement during the comparison stage. Furthermore, the camera quality is substantial. The outcome of the proposed work indicates that a new paradigm of nail monitoring could be used instead of physical and naked-eye inspection to detect and compare ridges and lines in fingernails. Thus, this method can be incorporated into clinical practice for further assessment and does not require highly trained staff to operate.

List of Abbreviations

- EHD: Edge Histogram Descriptor,
- HROD: Histogram of Ridges Orientation Delineate,
- BP: Bit-Point,
- IPT: image processing technique,
- CBIR: Content-Based Image Retrieval and
- HROD: Histogram of Ridges Orientation Delineate.

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DECLARATION STATEMENT

Funding Grants	No, I did not receive.
Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	Yes, the experimental protocol was approved by the Taif University Ethics Committee (No. 44-283). The committee for Bioethics with No. (HAO-02-T-105) and the committee considered that the proposal fulfils the requirements of Taif University; accordingly, ethical approval was granted (from March 23rd).
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	As the only author, I have approved the final version of the manuscript and agree to be accountable for all aspects of this work.

REFERENCES

1. Shari, R. and Richard, K.: Evaluation of nail lines: Colour and shape hold clues. *Cleveland Clinic Journal of Medicine*, 83 (5) 385-391, May (2016) https://doi.org/10.3949/ccjm.83a.14187
2. Scher, R.K., Rich, P., Pariser, D. and Elewski, B.: The epidemiology, aetiology, and pathophysiology of onychomycosis. *Semin Cutan Med Surg*; 32(suppl 1):S2–S4, (2013) https://doi.org/10.12788/j.sder.0014
3. Teach Me Anatomy, The Nail Unit. Part of the TeachMe Series, https://teachmeanatomy.info/upper-limb/misc/nail-unit/
4. David, S.: What to Do if Your Client Has Beau's Lines. Feb 11th (2019)
5. Tzu-Chuan, H. and Tsu-Yi, C.: Mees lines and Beau lines after chemotherapy. *CMAJ* February 23, 182 (3) (2010) https://doi.org/10.1503/cmaj.090501
6. Fawcett, RS., Linford, S., and Stulberg, D.L.: Nail abnormalities: clues to systemic disease. *Am Fam Physician*; 69:1417–24 (2004)
7. Hinds, G. and Thomas, VD.: Malignancy and cancer treatment-related hair and nail change. *Dermatol Clin*, 26:59 68 (2008) https://doi.org/10.1016/j.det.2007.08.003
8. Piraccini, B. M. and Iorizzo, M.: Drug reactions affecting the nail unit: diagnosis and management. *Dermatol Clin*, 25:215–21 (2007) https://doi.org/10.1016/j.det.2007.01.006
9. Minisini, AM., Tosti, A., Sobrero, AF. et al.: Taxanes-induced nail changes: incidence, clinical presentation and outcome. *Ann Oncol*, 14:333–7 (2003) https://doi.org/10.1093/annonc/mdg050
10. Lawry, M. A., Haneke, E., Strobeck, K., Martin, S., Zimmer, B. and Romano, P.S.: Methods for diagnosing onychomycosis: a comparative study and review of the literature. *Arch Dermatol*, 136:1112–1116 (2000) https://doi.org/10.1001/archderm.136.9.1112
11. Zaiac, MN. and Walker, A.: Nail abnormalities associated with systemic pathologies. *Clin Dermatol*, 31:627–649 (2013) https://doi.org/10.1016/j.clindermatol.2013.06.018
12. Scher, R.K., Daniel, C.R.: Nails Diagnosis, Therapy, Surgery. *3rd ed. Oxford*: Elsevier Saunders, (2005) https://doi.org/10.1016/B978-141602356-2.50003-7
13. Roberts, D.T., Evans, E.G.: Subungual dermatophytoma complicating dermatophyte onychomycosis. *Br J Dermatol*, 138:189–190 (1998) https://doi.org/10.1046/j.1365-2133.1998.02050.x
14. Sigurgeirsson, B.: Prognostic factors for cure following treatment of onychomycosis. *J Eur Acad Dermatol Venereol*, 24:679–684 (2010) https://doi.org/10.1111/j.1468-3083.2009.03487.x

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