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ORIGINAL ARTICLE

Monitoring of functional blood flow on human hand due to effect of different treatments by laser biospeckle imaging

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Abstract

In the proposed work, we report on qualitative as well as quantitative biospeckle monitoring of functional blood flow on the human hand. Intensity-based algorithms namely generalized difference and our earlier proposed algorithm parameterized global-average Fujii have been approached for the first time to analyze various physiological changes due to effect of different treatments such as hot and cold water treatments on the palm which can be helpful in examining cardiovascular and related diseases. In addition, blood flow has been monitored for the first time on face scrub, beauty creams, and pain relief ointments applied over the back of the palm. It has been found that, on application of four beauty creams namely Fair & Lovely, Ponds White Beauty, Vicco Turmeric, and Lotus Herbals Safe Sun on the back of the palm, blood flow increases and becomes highest (mean activity, 154.87) for Fair & Lovely among the four beauty creams. In addition, pain relief ointments such as Volini, Fast Relief, Molid Gel, and Zandu Gel increase blood flow after their applications on the back of the palm and Volini gives maximum increase of average blood flow (31.59) and hence can be considered one of the best among the four ointments. It has been further concluded that the person having more hemoglobin (14) and higher blood pressure (120/90) may have more blood flow or mean activity (85.80). In addition, it has been also concluded that although hot and cold water treatments can be used for increment in blood flow, temperature should be retained according to need and sensitivity of the sample.

Keywords Laser biospeckle imaging · Functional blood flow · Intensity-based algorithms · Cardiovascular disease

Introduction

In most optical techniques, either the Doppler effect [1] or the temporal statistics of time-varying laser speckle [2] has been used to monitor blood flow. Doppler effect has been used for capillary blood flow measurement which has been a great interest to clinicians in the diagnosis of vascular diseases. Forrester et al. compared laser speckle imaging (LSI) and laser Doppler perfusion imaging (LDPI) and found that higher temporal resolution of the laser speckle imager was more sensitive to measure the hyperemic response immediately following occlusion in comparison to LDPI [3]. It has been also shown by them that LSI gives higher resolution and quicker response time, which provides a significant advantage over LDPI for some application [4]. Laser speckle technique is a non-invasive, non-contact, and non-destructive technique to detect the biological vitality [5]. The technique has been used for quality analysis of fruits and vegetables [6, 7] and for assessment of biological leaf tissue [8]; viable and non-viable seeds have been classified with different specific humidity levels using this technique [9]. Sierra-Sosa et al. used this technique for localized analysis of paint coat drying [10]. Kumari and Nirala [11] used this technique for studying drying process of adhesives on plywoods. Qiu et al. used this technique for spatiotemporal laser speckle contrast analysis for blood flow imaging with maximized speckle contrast [12]. This technique has also been used to monitor capillary blood flow using sLASCA and tLASCA [13] and used in a modified form with improved spatial resolution [14]. Ansari et al. reported on laser speckle technique to detect drug action in *Trypanosoma cruzi* parasites through motion history image method [15]. Perfusion in hand surfaces has been found related to the vasculature network, blood flow, blood pressure, and tissue metabolism [16].

The present study deals with blood flow monitoring on the human hand during various physiological changes due to the effect of different treatments on the palm non-destructively

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Table 1 Details of scrub, beauty creams, and pain relief ointments

Scrub	Company name	Uses	Composition
Lotus Herbals Fresh Apricot Scrub (http://www.lotusherbals.com/apriscrub-fresh-apricot-scrub.html)	Lotus Herbals Limited, India	Removes dead skin cells, deeply cleanses the skin, restores skin moisture, nourishes and cleanses skin, improves skin complexion, soothes irritation	Walnut shells, cetyl alcohol, elderflower extracts, and glycerin
Beauty creams	**Company name**	**Uses**	**Composition**
Fair & Lovely (https://www.fairandlovely.in/)	Hindustan Unilever Ltd., India	Calm and soothes skin, clears marks and uneven skin tone, balances skin tone and rejuvenates skin mainly for marks, sun tan, darkness, dark circles, and dullness	Niacinamide, sodium ascorbyl phosphate (vit C), tocopherol (vit E), pyridoxine allantoin, titanium dioxide, and isopropyl myristate
Ponds White Beauty (https://www.ponds.com/in/products/collection/white-beauty/white-beauty-day-cream.html)	Multinational corporation Unilever, USA	Instant glow, flowery scent have pro-vitamin B3 + multiple UV protection, out skin tone, keeps skin safe from damaging UV rays	water, stearic acid, and palmitic acid, niacinamide (vitamin B3), glycerin, titanium dioxide, aluminum hydroxide, stearic acid, sodium ascorbyl phosphate, butyl methoxydibenzoylmethane, allantoin, cetyl alcohol, sodium starch octenylsuccinate, *Zea mays* (corn) starch, lycopene, glucose, sodium ascorbate, tocopherol, fragrance
Vicco Turmeric (https://www.sastasundar.com/index.php/product/details/vicco-turmeric-skin-cream/10307)	Vicco Group of Companies, India	Moisturizes skin and protects; keeps skin healthy and beautiful; treats skin problems like acne and pimple; prevents and cures skin infection, inflammation, blemishes, wounds, and other skin disorders; soothes boils and burns; nourishes the skin; improves value; and makes skin beautiful and fair	Extracts of *Cumcuma longa* (turmeric), sandalwood oil, potassium hydroxide, stearic acid, sorbitol, sodium hydroxide, benzyl alcohol, sodium methyl paraben, sodium propyl paraben
Lotus Herbal Safe Sun (http://www.lotusherbals.com/lotus-herbals-safe-sun-skin-lightening-anti-tan-sunblock-pa-spf-30.html)	Lotus Herbals Limited, India	High UVA and UVB protection; tan prevention, skin-lightening benefits; sun spots and sunburn protection; mattifying	Water, talcum, kaolin light, glycerine, polyacrylamide C13–14 isoparaffin laureth-7, oxybenzoene, octyl methoxy cinnamate, titanium dioxide, butyl, methoxydibenzoylmethane, isopropyl myristate, cyclopentasiloxane, elcosene, copolymer, fumed silica, 2-phenoxyethanol, methyl paraben, propyl paraben, methyl chloroisothiazolinone and methyl isothiazolinone, red iron oxide, yellow iron oxide
Pain relief ointment	**Company name**	**Uses**	**Composition**
Volini Gel (https://www.tabletwise.com/volini-gel)	Ranbaxy Laboratories Ltd., India	Pain due to soft tissue injuries, back pain, musculoskeletal aches	Diclofenac diethylamine BP 1.16% *w/w*, linseed oil BP 3.00% *w/w*, methyl salicylate IP 10.00% *w/w*, menthol IP 5% *w/w*
Fast Relief (http://www.emamiltd.in/brands/76/171/fast-relief-pain-relief-ointment.php)	Emami Limited, India	Arthritis, joint pains, muscular pain, backache, sprain, and strain	Wintergreen oil, menthol, eucalyptus oil, camphor, turpentine oil, clove oil, thymol
Zandu Gel (http://www.zanduayurveda.com/products/79/zandu-gel.php)	Emami Limited, India	Back pain, knee pain sprains, joint pain, ankle pain	M. salicylate 17.00%, menthol 11.50%, karpoor 2.00%, Nilgiri Tel 2.00%, Tarpinka Tel 0.50%, Lavangka Tel 0.50%, Ginger oleoresin 14%, WS 0.20%, benzyl alcohol (preservative) 0.50%, rosemary oil 1.00%, vitamin E nicotinate 0.08%, flaxseed oil (Atasikatel) 3.00%, Ajowankaphool 0.20%, Sallaki Guggal 2.00%, capsicin extract 0.02%
Molid Gel (http://www.gmhpharma.com/ointment-section.html)	GMH Laboratories, India	Joint pains and inflammation, back ache, sprains, strains, myositis, fibrositis	Linseed oil 3%, diclofenac diethylamine 1.16%, eq. to diclo. sodium 1% + methyl salicylate 10% + menthol 5% + benzyl alcohol 1%

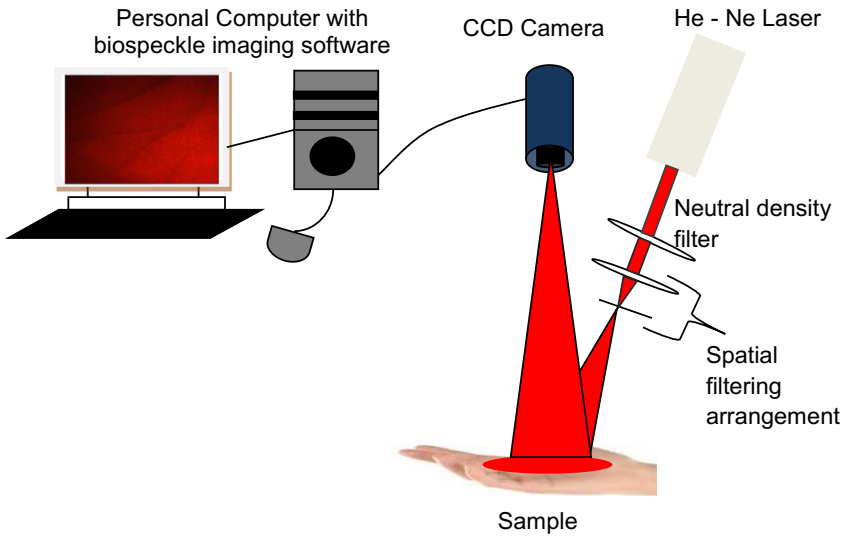


Fig. 1 Experimental setup to capture biospeckle images of the palm during various physiological changes

using intensity-based algorithms. In the proposed work, several existing intensity-based algorithms namely Fujii, Parameterized Fujii, Inverse Fujii, Weighted Parameterized Fujii, and Parameterized Temporal Difference methods have been applied by us for the blood flow monitoring but their results are abrupt and noisy, and do not lead to a definite conclusion. Only two algorithms such as existing generalized difference (GD) [17] and parameterized global average Fujii (PGAF) [18] have been found applicable for monitoring of functional blood flow quantitatively as well as qualitatively. Blood flow has been monitored during various physiological changes of the human body such as for hot and cold water treatments. In addition, blood flow has been monitored for the first time on beauty creams, pain relief ointments, and scrub applied on the palm. Furthermore, blood flow (BF) has been correlated with blood pressure (BP) and hemoglobin (Hb).

Materials and methods

Different treatments

Hot and cold water treatments

Healthy blood flow can affect everything such as blood pressure and also our risk of cardiovascular disease. Hot

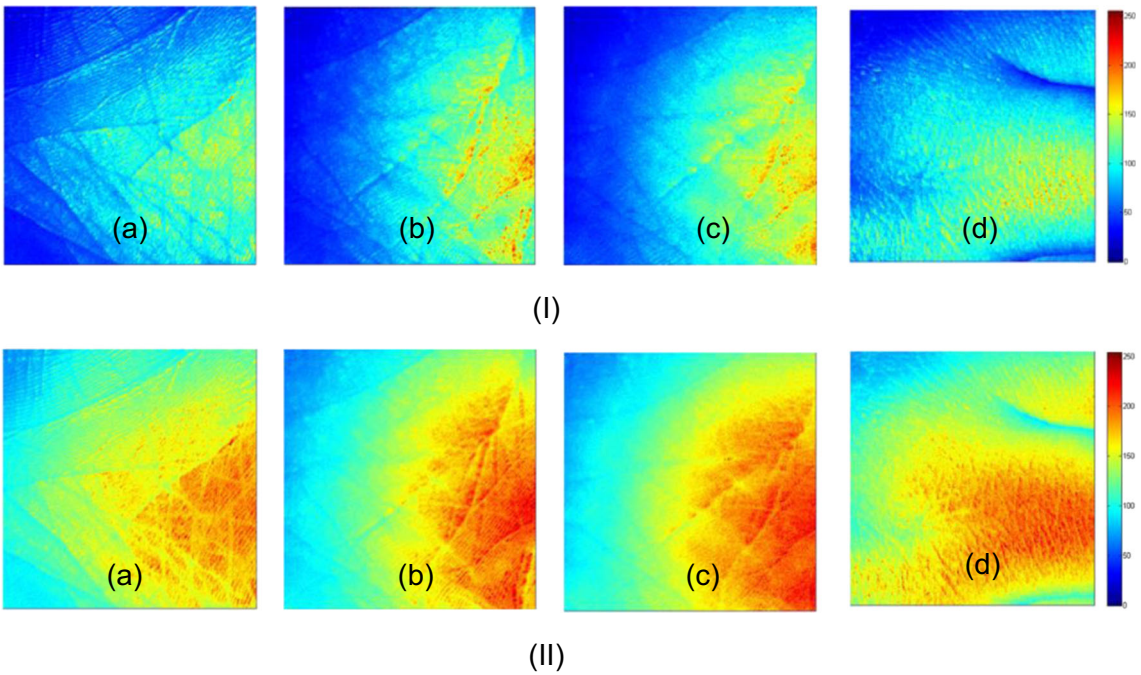


Fig. 2 Spectral maps obtained for **a** normal front palm, **b** hot water treatment, **c** cold water treatment, and **d** normal back of the palm using **(I)** GD and **(II)** PGAF at $p = 0.5$

Table 2 Mean activity difference between normal front palm and different treatments

	Mean activity (GD)	Mean activity difference between normal palm and treatment	Mean activity (PGAF)	Activity difference between normal palm and treatment
Normal front palm	78.33	0	137.61	0
Hot water treatment	85.77	7.44	138.50	0.89
Cold water treatment	87.02	8.69	141.53	3.92

water plays an important role in increasing and circulating blood more effectively throughout the circulatory organs, arteries, and veins and our body. Thermal vasodilatation following warm-water bathing is good for improvement in cardiac function for a patient [19]. Cold exposure to a small surface area produces compensatory vasodilatation in the deeper vascular system due to which blood flow increases to the tissues underlying the site of exposure. This vascular reaction is helpful to maintain constant deep tissue temperature [20]. Cold water treatment includes the benefits of overall blood circulation to help alleviate persistent cold hands or feet. The hand has been kept in hot water or cold water for exposure of 1 min. The hot and cold water treatments have been discontinuously monitored while waiting in between for 30 min for each experiment. The temperature range was 30.7 to 50 °C at the interval of 5 °C for hot water treatment and 5 to 30.5 °C at the interval of 5 °C for cold water treatment.

Scrub, beauty creams, and pain relief ointment treatment

The details of composition, uses, and manufactures of scrub, beauty creams, and pain relief ointments have been provided in Table 1.

Scrub, beauty creams, and ointment provided in Table 1 were applied over a human's back of the palm. The time gap between each application of creams and ointments was nearly 2 h. The data were taken after complete removal of the creams using standard Dettol skin care everyday protection PH-balanced hand wash. The same hand was used for each agent.

Relation among BP, Hb, and BF

Higher blood pressure is the indicator of increasing blood flow and hemoglobin levels in peripheral blood are positively correlated with blood pressure levels. The increase of pressure may

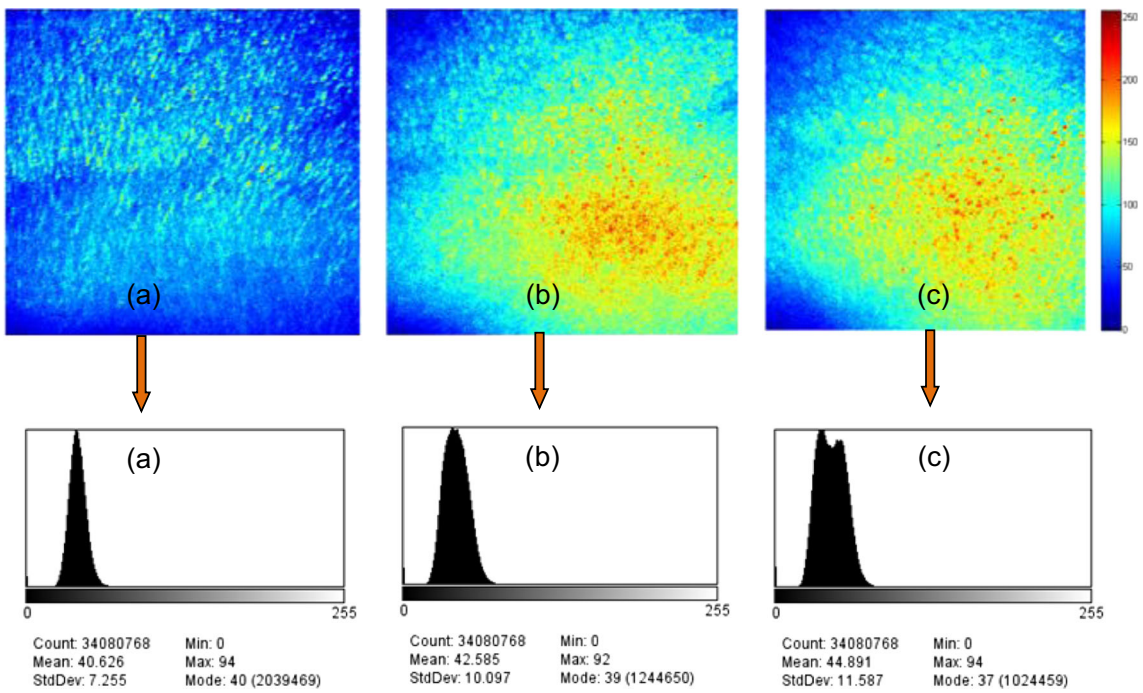


Fig. 3 Spectral maps obtained using GD for **a** normal back of the palm, **b** scrub massaged over the back of the palm for 20 min and **c** scrub massaged over the back of the palm for 25 min with their corresponding histograms, respectively

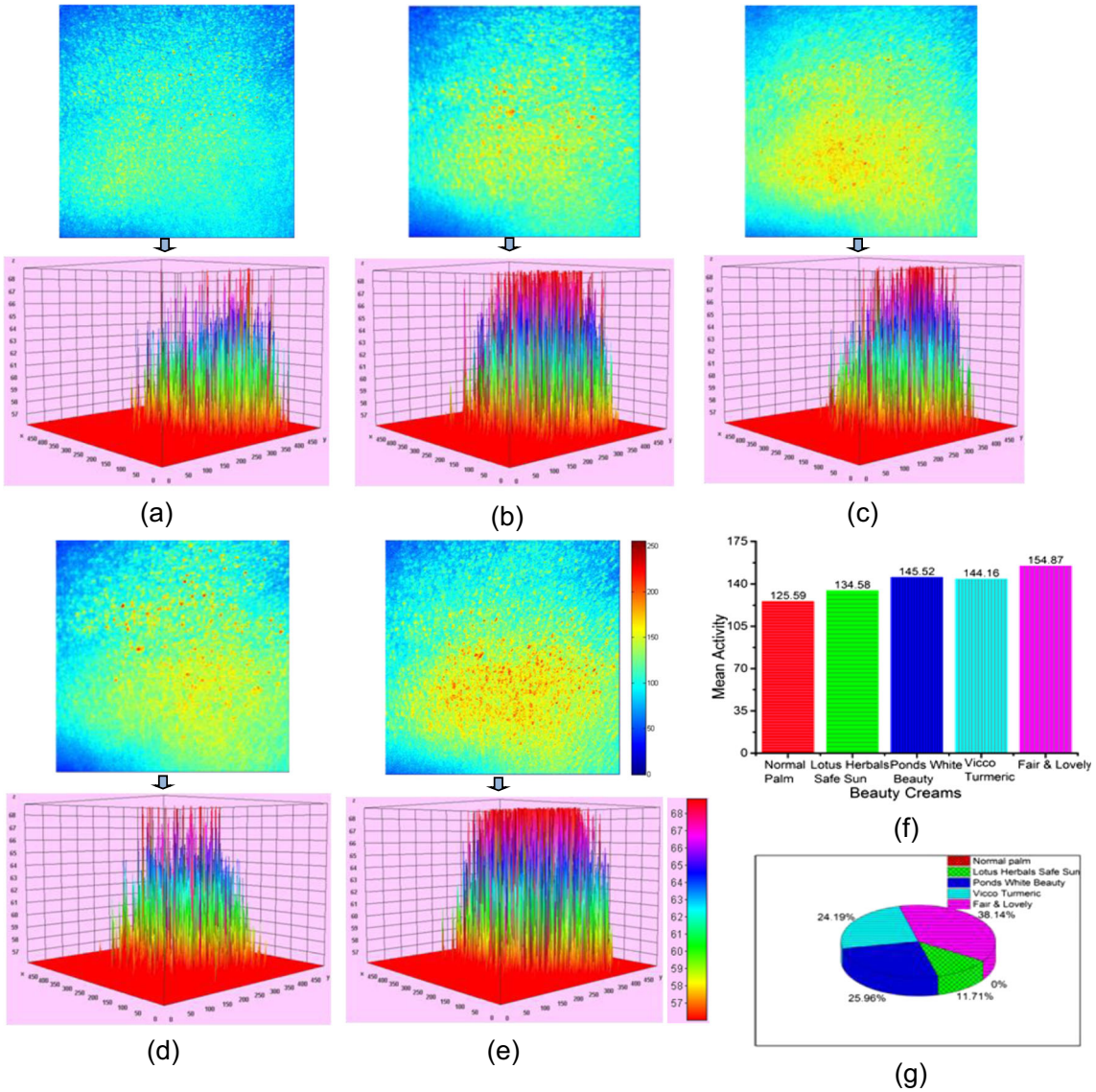
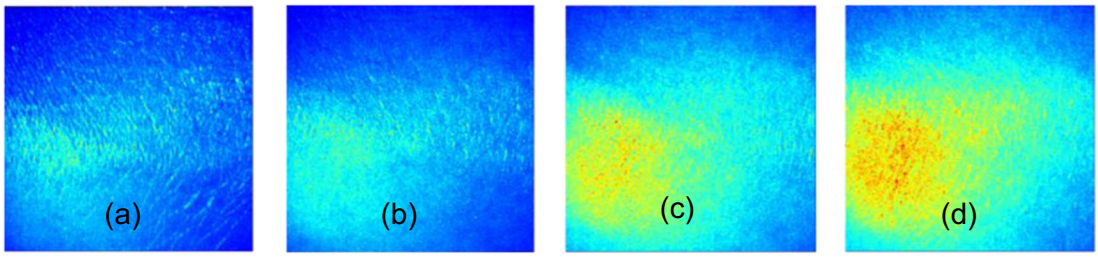


Fig. 4 Spectral maps obtained from GD for **a** normal back of the palm, **b** with Lotus Herbals Safe Sun, **c** with Ponds White Beauty, **d** with Vicco Turmeric, and **e** with Fair & Lovely massaged over the back of the palm for 10 min along with 3D graphs of biospeckle images of each corresponding cream applied over the back of the palm, respectively. **f** Bar chart of mean activity obtained for the normal palm and different creams massaged over the palm. **g** Pie chart obtained for mean activity difference of normal palm and cream massaged over the back of the palm (%)

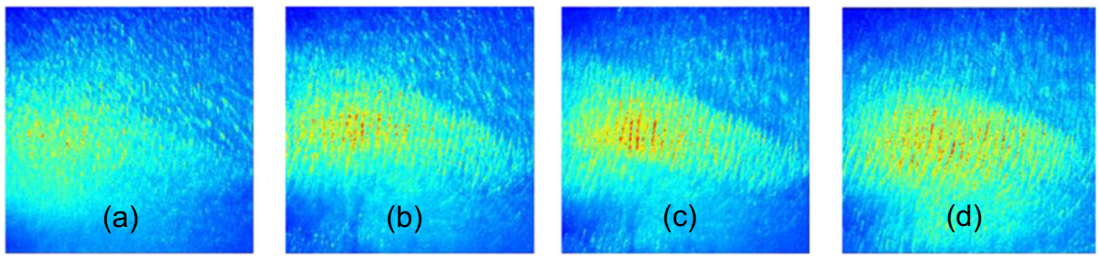
be mainly due to the hypertension. Hypertension is also known as high blood pressure which can cause several complications such as heart disease, stroke, and death [21, 22]. BP measurement has been done using a sphygmomanometer with the help of a medical expert. Hb test was done from a standard laboratory. BF was obtained from results extracted using processed data.

Experimental setup

Figure 1 represents the schematic of the experimental arrangement for biospeckle recording. The test specimen is illuminated using a He-Ne laser (Newport Corporation) of wavelength 632.8 nm and power 10 mW. Expanded and spatially filtered light beam has been allowed to fall on the rough surface of the human hand. Intensity has been adjusted throughout the experiment using neutral density filter. CCD camera (Basler scA1300-32fc FireWire, Germany) having resolution of 1294 × 964 pixels with frame rate 32 fps and pixel size 3.75 × 3.75 has been used to capture the sequential images of 512 × 512 pixels. A set of 128 images of 8-bit digitized images were acquired at every 80 ms. The whole experimental work was performed in the dark and on vibration isolation table at room temperature. The distances from the CCD camera to the target area (palm) and from the target area to the He-Ne laser were 35 cm and 56 cm respectively. The angle of illumination of the laser beam with the CCD camera was maintained at 35° to


(a)
(b)
(c)
(d)

(I)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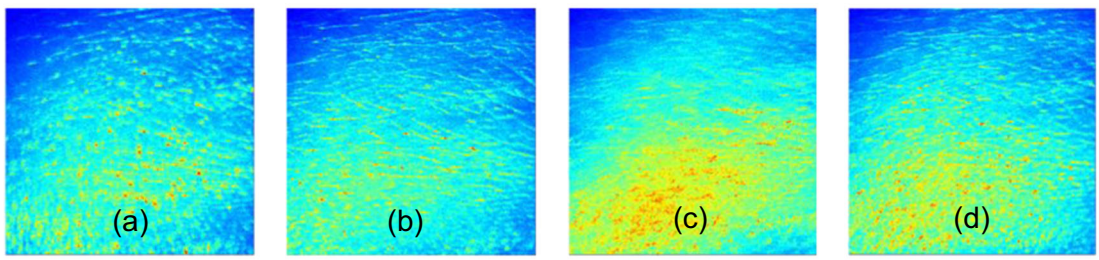
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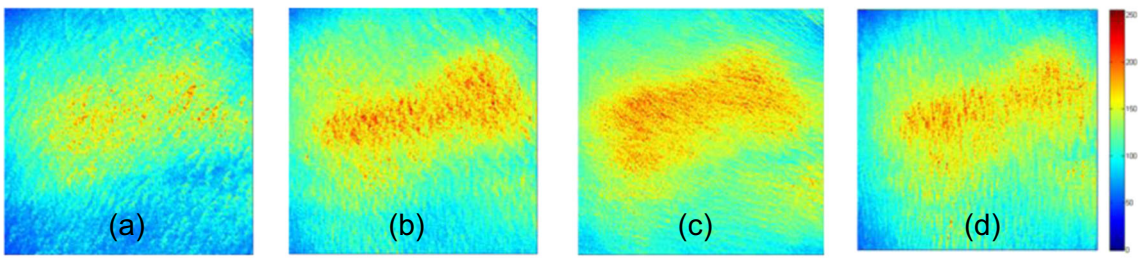
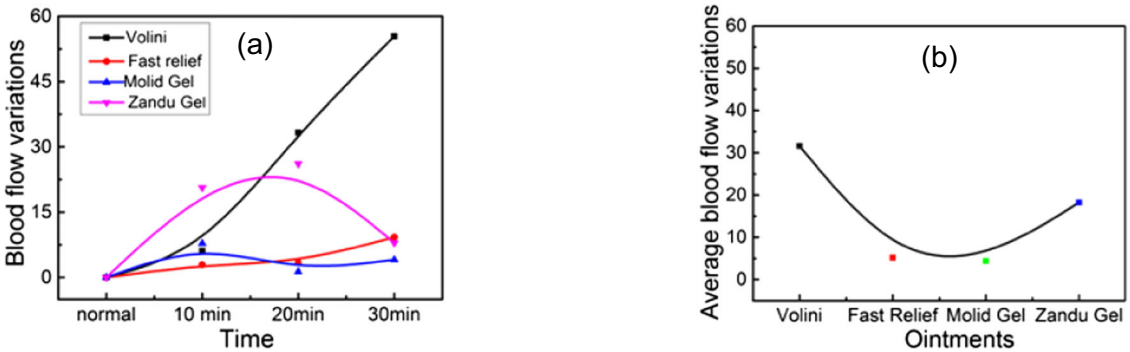

(a)
(b)
(c)
(d)

(IV)


(a)
Volini
Fast relief
Molid Gel
Zandu Gel
Blood flow variations
60
45
30
15
0
normal
10 min
20min
30min
Time
(b)
Average blood flow variations
60
50
40
30
20
10
0
Volini
Fast Relief
Molid Gel
Zandu Gel
Ointments

(V)

◀ **Fig. 5** Spectral maps obtained using GD for (**I**) Volini, (**II**) Fast Relief, (**III**) Molid Gel, and (**IV**) Zandu Gel on **a** normal back of the palm and ointment applied on the palm with passage of time at **b** 10 min, at **c** 20 min, and at **d** 30 min, respectively. (**V**) Plot of **a** blood flow variations versus time and **b** average blood flow variations versus ointments

capture high-contrast images and to minimize specular reflection of light. All the experiments have been performed on seven healthy volunteers of different genders (male and female) and age groups repeatedly. The four male genders of ages 23 years old, 27 years old, 30 years old, and 57 years old and three female genders of ages 26 years, 27 years, and 29 years participated in the experiment. The average age is 31.28 years.

Algorithms to process biospeckle images

Existing algorithms

GD GD has been used for biospeckle activity (BA) analysis of fruits [23] and activity analysis of root tissues [24], etc. In the present paper, the given algorithm has been used for functional blood flow monitoring in the human hand.

The equation is defined as:

$$GD(x,y) = \sum_{k}\sum_{l}|I_k(x,y) - I_{k+l}(x,y)| \quad (1)$$

Where, k and l are the image sequence. If k is fixed and l is varying, then I_{k+l} represents the intensity matrix of successive images in the image sequence followed by I_k.

PGAF PGAF has been used to distinguish between the two regions namely bruised and fresh regions of Indian Apple [18]. In this paper, this algorithm has been used for functional blood flow monitoring in the human hand.

The equation is given:

$$PGAF(x,y,p) = \sum_{k}\left|\frac{I_1(x,y) + I_2(x,y) + \ldots + I_n(x,y)}{n} - I_k\left(x,y\right)\right|^p \quad (2)$$

Where, p is a parameter whose value may be a positive integer as well as fraction for *PGAF*.

Results and discussion

Qualitative as well as quantitative analysis—comparative analysis between algorithms

Figure 2 shows the spectral maps obtained for normal palm, hot water treatment, cold water treatment, and normal back of the palm with activity color bar using GD and PGAF. In color bar, red color shows the highest contrast with more blood flow and blue color shows the lowest contrast with less blood flow. More blood flow has been found for hot water treatment and cold water treatment in comparison to normal front palm. Furthermore, it has been also observed that more blood flow has been found on normal back of the palm in comparison to normal front of the palm.

On comparing the results, it has been found that GD gives better result than PGAF with more contrast and relatively higher mean activity difference between normal palm and different applications as shown in Table 2. However, the activity maps generated using PGAF give also good visualization keeping the resolution the same as obtained for GD.

Effect of scrub on the back of the palm

Figure 3 shows the spectral maps obtained using GD for normal back of the palm and scrub massaged over the back of the palm with passage of time. From the figure, it is clearly visible that BA increases and hence blood flow also increases when scrub is massaged over the palm. In addition, increase in mean values and therefore increased brightness as well as broadening of histogram also indicates increase in blood flow for scrub applied on the back of the palm.

Effect of beauty creams on the palm

Figure 4 shows the spectral maps obtained using GD for normal back of the palm and different beauty creams applied over it for 10 min. It is evident from the spectral maps that BA increases and hence blood flow increases when beauty creams are applied over the back of the palm. On comparative analysis, it is concluded that blood flow increases maximum for Fair & Lovely applied over the back of the palm among the four creams. In addition, Fig. 4 also shows the 3D graphs of

Table 3 Correlation among BP, Hb, and BF

Palm with treatments	BP, Hb, and BF (obtained using GD) for		
	29-year-old female hand	27-year-old male hand	26-year-old female hand
Normal palm	BP 110/70, Hb 12.5, BF 78.33	BP 120/90, Hb 14.0, BF 85.80	BP 100/70, Hb 11.0, BF 71.53
Hot water treatment	BP 110/90, BF 85.77	BP 120/95, BF 93.71	BP 110/70, BF 92.43
Cold water treatment	BP 120/90, BF 87.02	BP 125/100, BF 106.07	BP 100/80, BF 91.88

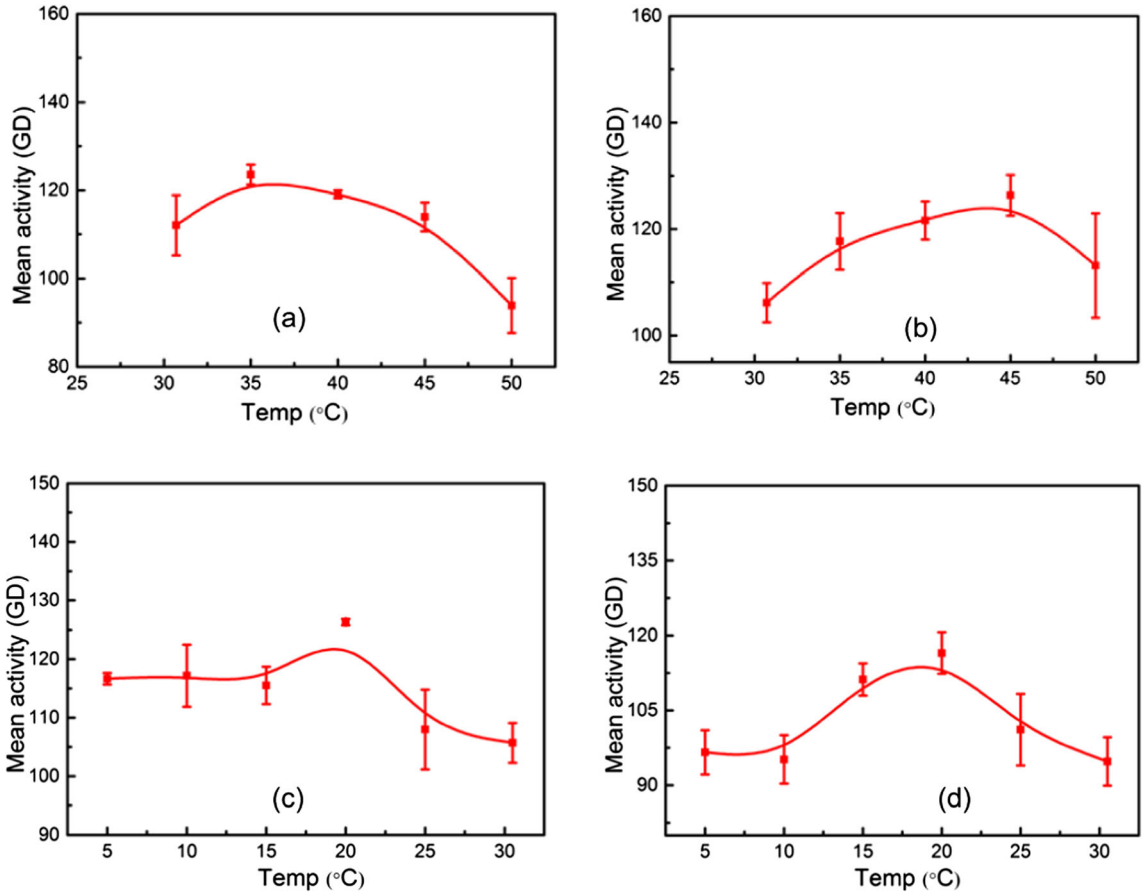


Fig. 6 Graph between mean activities obtained using GD versus hot water treatment for **a** 29-year-old female palm, **b** 26-year-old female palm; and cold water treatment for **c** 29-year-old female palm, **d** 26-year-old female palm with increasing temperatures

biospeckle image for normal back of the palm and the different creams applied over the palm. The activity on the whole surface of blood is seen as a peak of the 3D image that increases when the cream is applied over it. The plateau raises maximum for Fair & Lovely. Hence, we can conclude that blood flow increases maximum for Fair & Lovely applied over the palm. Figure 4f shows the bar chart of mean activity obtained for the normal palm and different creams applied over the normal palm. Mean activity has been found maximum for Fair & Lovely and hence it can be used for maximum increment in blood flow. From the pie chart as indicated in Fig. 4g, it is evident that Fair & Lovely contributes the highest blood flow variation among all the four creams.

Effect of pain relief ointments on the palm

Figure 5 (I–IV) shows the spectral maps with increasing time obtained using GD for the ointments rubbed over the back of the palm. From the spectral maps, it is found that BA increases and hence blood flow increases with the passage of time for all the four ointments. Blood flow becomes higher in the back of the palm after massaging the ointment. Moreover, blood flow variations, i.e., difference of mean activities, obtained for normal palm to ointment applied palm have been calculated for each ointment for time intervals shown in V(a) and then average blood flow variations have been calculated for all the four ointments separately and plotted in V(b). V reveals that the maximum blood flow variation is for Volini (31.59) and minimum is for Molid Gel (4.4); and hence, it can be concluded that Volini is one of the best ointment for increment in blood circulation

Quantitative analysis

Relation among BP, Hb, and BF

BP, Hb, and BF corresponding to different treatments have been measured for all the healthy volunteers. The results are shown in Table 3.

From Table 3, it is observed that blood pressure has been found to increase with hot water and cold water treatments. In addition, it is also concluded that if BP and Hb are high, BF is also found to be high. Furthermore, it is also found that increase in BF is almost the highest for cold water treatment.

Hot and cold water treatments

We have taken the data for healthy volunteers for both hot and cold water treatments. Results for hot and cold water treatment are shown.

Graphs have been plotted in Origin and fit adjustment has been done using the line joining B-spline curves. Graphs in Fig. 6a and b show hot water treatment for 29-year and 26-year-old female palms, respectively. It is observed that blood flow increases up to 35 °C and then decreases; however, value of blood flow remains more than that of normal palm up to 45 °C and then decreases at 50 °C for the 29-year-old and increases up to 45 °C and then decreases at 50 °C for the 26-year-old female palm; however, value of blood flow remains more than that of normal palm up to 50 °C. The reason behind the decreasing nature of the blood flow after a certain temperature may be attributed to the sensitivity of the sample for hot water. It is further concluded that though blood flow increases after hot water treatment, burning sensation may cause decrease in mean activity and hence less blood flow is obtained for 29-year-old female palm at 50 °C. Therefore, it is concluded that for therapeutic effect of hot water on human skin, an appropriate temperature and their variations should be selected according to the need and sensitivity of the sample. Graphs in Fig. 6c and d show cold water treatment for 29- and 26-year-old female palms, respectively. Blood flow almost increases for cold water treatment for both the samples in comparison to normal palm. The normal room temperature was 30.6 °C.

Conclusions

These are the conclusions made on the basis of the results after the experiment performed and analysis done.

- GD and PGAF have been used for the first time to monitor blood flow in the human hand during different treatments. Comparative study between the results obtained using the two algorithms reveals that GD gives better result than PGAF with more contrast and relatively higher mean activity difference between the normal palm and the palm with different applications.

- Scrub, beauty creams, and pain relief ointments can be used to increase blood circulation. The blood flow has been found to increase on application of four beauty creams, namely, Fair & Lovely, Ponds White Beauty, Vicco Turmeric, and Lotus Herbals Safe Sun, and has been found maximum for Fair & Lovely with the highest mean activity (154.87). Furthermore, the blood flow also increases for all the four ointments namely, Volini, Fast Relief, Molid Gel, and Zandu Gel on their application on the palm and Volini gives the maximum increase of average blood flow (31.59) and hence can be considered one of the best among them.

- The person having more hemoglobin (14) and higher blood pressure (120/90) may have more blood flow (mean activity, 85.80). This may be useful for the treatment caused by hypertension.

- Hot and cold water can be useful to treat cardiovascular and other related diseases. In addition, it is also concluded that though hot and cold water are used for therapeutic treatment, temperature should be appropriate and temperature variation should be decided according to the need and sensitivity of the sample.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval We certify that, although the research has been carried out on the human hand, no harmful treatment has been done. All the volunteers were healthy and all the treatments done on them were safe and non-destructive, and hence ethical approval is not needed for this study.

Informed consent Informed consent was received from all individual volunteers in the study.

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