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Improving the Detection of Stage I Pressure Ulcers by Enhancing Digital Color Images

Prabhu Jude Rajendran, Jon Leachtenauer, Steve Kell, Beverely Turner, Chris Newcomer, Courtney Lyder, Majd Alwan, *Senior Member, IEEE*

Abstract— **It has been observed in previous studies that the detection of Stage I pressure ulcers becomes more difficult by unaided visual inspection and/or by using currently available techniques with darker skin subjects, due to increased melanin content. This difficulty is indicated by the elevated proportion of black and Hispanic patients developing more serious Stage III and IV pressure ulcers compared to white patients. The ultimate goal of this project, undertaken by MARC at the University of Virginia, is to develop a low-cost, non-contact imaging-based Stage I Pressure Ulcer detection system for use by support staff in assisted living and skilled nursing facilities to increase the ulcer detection rate over a wide range of skin colors. This paper describes an image enhancement procedure that improves the detection of pressure ulcers when applied to the color images of ulcer sites. Preliminary results clearly indicate that the enhanced images exhibit higher contrast and make the pressure ulcer site more conspicuous to the examiner. The experiments show promising results even for subjects with black and dark brown skin colors.**

***Index Terms*— Emerging Technologies, Image Enhancement, Non-Contact Imaging-Based Detection Methods, Pressure Ulcer, Color Images.**

I. Introduction

Treatment of pressure ulcers was estimated to cost Medicare $1.34 billion dollars per year [1]. Pressure ulcers, also called bedsores, occur when unrelieved pressure results in constriction of blood vessels, which in turn starves the skin of oxygen and other nutrients [2]. Pressure ulcers typically form over bony protrusions. If the initial constriction, observable as erythema, is not diagnosed, the skin may ulcerate. Ultimately, underlying tissue and even bone may ulcerate. Not only are pressure ulcers costly, but they are associated with increased mortality [3]. Early detection is thus critical in reducing pain and suffering associated with pressure ulcers, as well as reducing treatment costs.

Although erythema is generally readily detectable as persistent redness in light-pigmented subjects (low melanin levels), it is more difficult to detect in dark-skinned subjects. The difficulty is suggested by the results of a study conducted by the U.S. Centers for Medicare and Medicaid Services (formerly Health Care Financing Administration) [4]. This study reported that the number of black and Hispanic patients who developed more serious Stage III and IV pressure ulcers was twice the number of white patients.

In keeping with its Eldercare technologies program, the Medical Automation Research Center (MARC) undertook a pilot study of erythema detection in the presence of high melanin levels. The ultimate goal of this project is to develop a low-cost, non-contact imaging-based erythema detection system for use by support staff in assisted living and skilled nursing facilities. Initial results are presented in [5]. This paper presents the preliminary results of applying image enhancement techniques as a means of improving erythema detection results over that achieved with unprocessed images.

II. Method

Reactive hyperemia was induced in twenty subjects following a simple indenting procedure. The indented area was imaged with an unfiltered digital camera. The RGB images were then enhanced following the procedure explained later in this paper.

A. Subjects

A sample of 20 subjects was used. Subjects were recruited based on skin color as defined by an experienced clinician. Subjects were classified as black, dark brown, brown, light brown, and pink. Four subjects were recruited for each category. Twelve subjects were males and eight were females. All subjects signed an IRB-approved informed consent form and were compensated for their participation. The experimental and data collection procedure took less than 30 minutes per participant.

B. Indenting Procedure

A 12mm sphere was used for indenting. The sphere (a glass marble) was placed in a hemispherical cavity mounted on a platform where the height could be adjusted. The subjects were instructed to place the back of their upper arm on the sphere at a point ~50mm beyond the point of the

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P. Rajendran is with the Electrical and Computer Engineering Department at the University of Virginia, Charlottesville, VA 22908 USA (e-mail: pjr5f@virginia.edu).
J. Leachtenauer volunteers at the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA through the Health System Volunteer Services (e-mail: jleachtenauer@adelphia.net).
S. Kell is with the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (e-mail: swk3f@virginia.edu).
B. Turner is with the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (e-mail: bt2h@virginia.edu).
C. Newcomer is with the University of Virginia School of Nursing, Charlottesville, VA 22908 USA (e-mail: cnewc@verizon.net)
C. Lyder is with the University of Virginia School of Nursing, Charlottesville, VA 22908 USA (e-mail: chl4n@cms.mail.virginia.edu)
M. Alwan is with the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (phone: 434-924-2265; fax: 434-924-5718; e-mail: ma5x@virginia.edu).

elbow and to keep their upper arm horizontal and their lower arm vertical. The weight of the arm supplied the indenting pressure (estimated as 50 mm Hg); subjects were instructed not to press on the marble. A two-minute indenting period was used. At the end of the period, the arm was placed horizontally on the platform for imaging with the forearm at an angle of 60 degrees or more relative to the upper arm. The clinician inspected the indent site before and after indentation and noted visible changes due to indenting.

C. Imaging Procedure

A digital camera (3.8 mega pixel CCD array with a response from ~ 400 nanometers to 850 nanometers) was used to acquire images in the visible region. Florescent overhead lighting was employed during the image capture and exposures were set to avoid saturation while maintaining dynamic range. Imaging distance was ~1m. Images were acquired in a 4:1 compression JPEG format. Compression at this rate has been shown to have minimal effect on image quality [6]. Tests run in the current study showed no apparent artifacts (TIFF/JPEG image subtraction) and R.M.S.E. values of less than 1.

Before indenting, the target indent area (one of the elbows) was imaged using the above-mentioned camera with and without filters (for this study, only the unfiltered RGB images were enhanced). The target area was then indented and imaged again. The process was then repeated for the other arm. The unfiltered visible images were saved as three separate R, G, B images. The acquired images covered more than just the target area of interest.

D. Image Enhancement

Three histograms, one for each of the R, G, B layers of the image, were generated for all the color images. The individual layers of the image were then stretched such that 1% of data was saturated at high intensities. Low intensities were not saturated to avoid loss of details in the dark intensity region. The three layers were then combined back to form a RGB image. Although the histogram stretching improved the contrast of the image, the indented site in images of the elbows of black and dark-brown post-indentation were still not conspicuous.

To improve the detection of pressure ulcers through aided visual inspection of the acquired images, the images required further enhancements. One of the most commonly used image enhancement algorithms is global histogram equalization [7], which adjusts the histogram to approximate a uniform distribution. The main disadvantage of this algorithm is that it treats all regions of the image equally and often yields poor local performance [8]. Since, in our case, the acquired RGB images covered more than just the target area of interest, the pixel intensities spanned a wide global dynamic range. Hence, the global histogram equalization could not enhance the image to a desired level of visual clarity, especially in images of subjects classified in the dark brown and black skin color categories.

Given this context, we needed to use an enhancement method that locally improves the contrast of the image. Adaptive Histogram Equalization (AHE), was explored as a local image enhancement algorithm. For this study, we decided to use Contrast Limited Adaptive Histogram Equalization (CLAHE), a variation of AHE, as it embodies the ability of AHE to generally perform better in images that have large global range, but have small local feature gray level variations [9] and also provides the ability to control the contrast limit to suit the image application requirements.

Initially CLAHE was performed by dividing each of the R, G, B layers (pre-stretched with 1% saturation in the high intensity region) of the color image, which was cropped to 400X650 pixel image, into 4 non-overlapping quadrants followed by equalization on individual tile histograms to improve the contrast. The four tiles are then re-combined using bilinear interpolation. The Contrast Enhancement Limit was set at 0.02 in all our experiments. The individual CLAHE-processed R, G, B images were then combined to form a contrast enhanced RGB image.

Though the indented sites appeared with a better contrast in the processed images, it was observed that this methodology introduced coloration artifacts in the image, which may in turn result in false positives. To overcome this drawback, we enhanced the images by performing Luminance-based CLAHE. In this approach, RGB images were converted into $L^*a^*b^*$ coordinates, the luminance layer of the image was adaptively enhanced by dividing the image into 16 (4x4) non-overlapping tiles of equal size and then equalizing the luminance histogram of individual tiles. The contrast enhancement limit was set at 0.05 for this approach. The selection of the tile divisions and contrast enhancement limit was based on subjective inspection of a sample set of enhanced images. The luminance-based CLAHE exhibited better performance in terms of making the indented site conspicuous even in darker skin images, in addition to overcoming the disadvantage of introducing coloration artifacts. Hence, we decided to apply the luminance-based CLAHE approach to study its effectiveness in improving the detection rate of pressure ulcers by visual inspection.

The enhancement in the contrast of the image was evaluated by measuring the luminance difference between the indented site and five control sites (not affected by the indentation, but in close proximity to the indent site) selected from the area around the indent site, in both the pre-enhancement and post-enhancement images. Square tiles (20x20) were selected at the indented and control sites, and the mean values of L^* in the corresponding regions were calculated. The luminance difference (ΔL^*) between the indented and the control sites is then computed by finding the difference between the mean L^* values in the selected tile on the indented site and the mean of their corresponding values in the control sites (adapted from [10]). The mean ΔL^* for the pre- and post-enhancement images are calculated by averaging the ΔL^* values computed at the 5 different control sites in the corresponding image. A contrast enhancement measure, which quantifies the effectiveness of the image enhancement in showing the indented site with higher contrast can then derived by computing the ΔL^*_{ratio} defined as:

$$\Delta L^*_{ratio} = \Delta L^*_{post-enhancement} \Big/ \Delta L^*_{pre-enhancement} \qquad (1)$$

where $\Delta L^*_{pre\text{-}enhancement}$ and $\Delta L^*_{post\text{-}enhancement}$ are mean ΔL^* values computed for the image pre- and post-enhancement respectively.

III. Results

A review of the processed images indicated that the indented areas showed higher contrast following the CLAHE enhancement of the pre-stretched images.

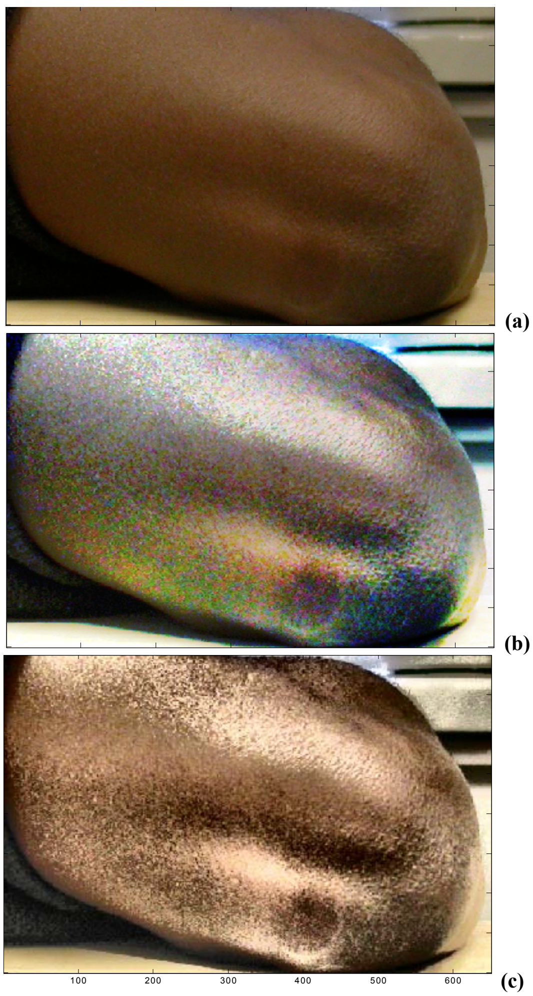

Fig. 1. a) Image of the Post-Indented Elbow of a Subject Classified in the Black Skin Color Category, b) individual layer CLAHE enhanced image with contrast enhancement limit of 0.02, and c) Luminance CLAHE enhanced image with contrast enhancement limit of 0.05.

Fig. 1 shows the pre-processed (a) the multilayer CLAHE enhanced image (b) and the luminance -based CLAHE enhanced image (c) of the post-indented right elbow of a subject classified in the black skin color category. The indented site, which appears as a slightly darker circular spot that is obscured by the dark background, becomes easier to identify in the enhanced images– Figs. 1b and 1c. However, the luminance-based CLAHE image gives a more natural image, devoid of coloration artifacts. Similar contrast enhancement was observed for other skin colors (dark brown, light brown, light pink) that we tested. Figures 2 and 3 show the results for a sample of subjects classified in the dark brown and light pink skin color categories respectively.

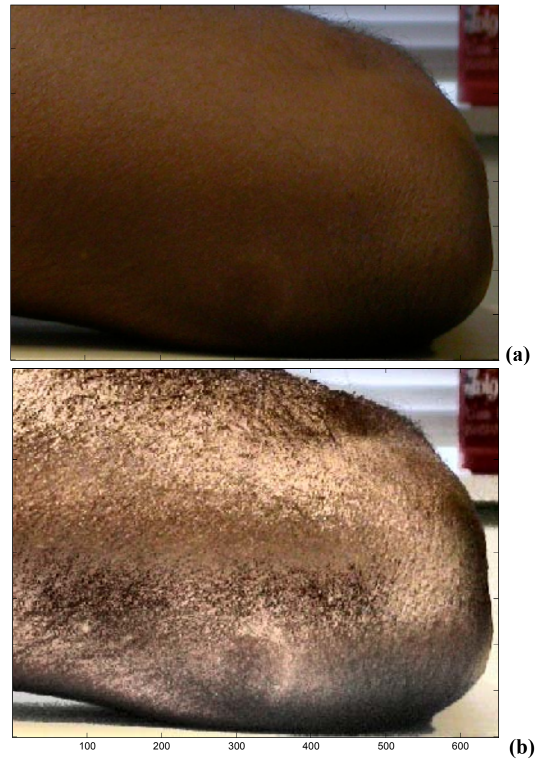

Fig. 2. a) Image of the Post-Indented Elbow of a Subject Classified in the Dark Brown Skin Color Category, and b) luminance based CLAHE enhanced image with Contrast Enhancement Limit of 0.05.

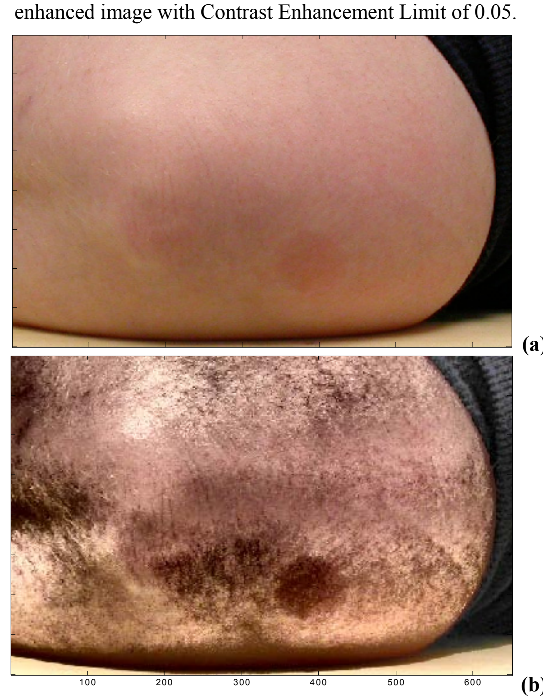

Fig. 3. a) Image of the Post-Indented Elbow of a Subject Classified in the Light Pink Skin Color Category, and b) the CLAHE enhanced image with Contrast Enhancement Limit of 0.02.

The effectiveness of the CLAHE in demarcating the indented sites is visually demonstrated by extracting a 200X200 square tile of a broadband image of a post-indented elbow of a subject classified in the black skin color category; the image is centered around the indented site (Fig. 4a) and it was enhanced using global histogram equalization on the image's luminance layer (as AHE is a process of applying global histogram equalization at pre-defined local regions). The enhanced image (Fig. 4b) clearly shows the indented area with a much higher contrast even for a dark skin tone, hence validating the feasibility of applying this method towards detection of Stage I Pressure Ulcers over a wide range of skin tones.

(a)

(b)

Fig. 4. a) A 200X200 square image of a Post-Indented Black Subject taken around the indented site before enhancement and b) after enhancement.

Table I shows the mean $\Delta L^*_{\text{pre-enhancement}}$, $\Delta L^*_{\text{post-enhancement}}$, as well as $\Delta L^*_{\text{ratio}}$ for the three images presented in this paper.

TABLE I

MEAN CONTRAST ENHANCEMENT

Sample	Mean $\Delta L^*_{\textit{pre-enhancement}}$	Mean $\Delta L^*_{\textit{post-enhancement}}$	$\Delta L^*_{\textit{ratio}}$
Black Skin (Fig. 1.)	11.6	73.5	6.3
Brown Skin (Fig.2.)	11.14	36.9	3.3
Pink Skin (Fig. 3.)	13.06	91.7	7.0

A *t-test* for means was used to compare $\Delta L^*_{\text{pre-enhancement}}$ and $\Delta L^*_{\text{post-enhancement}}$ for these images. The test showed that the change in ΔL^* as a result of the enhancement was statistically significant within each of three skin color categories presented in Table I. The test yielded a p value < .0001 (two-tailed) for all the images compared, indicating that the enhancement process has significantly improved the contrast of the images, and is likely to significantly improve visual detection by inspecting clinicians.

IV. CONCLUSIONS AND FUTURE WORK

The preliminary results confirmed that CLAHE-enhanced broadband images could show indented sites with much higher contrast than the preprocessed images. This promising observation was applicable to images of all the skin colors examined– black, dark brown, light brown and light pink. This suggests that erythema can be detected with relatively simple and low-cost imaging and image enhancement techniques, such as those applied in this study.

In the future, we intend to apply the enhancement methods presented here to all acquired images. In addition, similar enhancement techniques will be applied to images of indented sites acquired using other imaging modalities presented in [5], including infra-red imaging and filtered color images. The images, including the enhanced ones, will be reviewed by a sample of clinicians in a blind test to assess the sensitivity and specificity of the enhancement to quantify the estimated improvement in the Stage I Pressure Ulcer detection rate.

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