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Dynamic Illumination based System to Remove the Glare and Improve the Quality of Medical Images

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Abstract — **Medical images taken from camera based devices (e.g. laparoscope, colposcope, retinoscope, etc) are greatly affected by numerous bright reflection spots (called glare or specular reflections). This may affect the visibility of the abnormal features (if present in the glare locations). We have developed a novel solution to overcome this problem by incorporating a multi-LED lighting solution. This will intelligently and rapidly switch on and off the LED's in a pattern that dynamically and geometrically shifts/shuffles these glare spots back and forth in the image such that every glare-affected area of a single image frame can be reconstructed from a few adjacent time-frame images. We have built the prototype that successfully demonstrates how the glare problem in the medical video/image can be satisfactorily solved, significantly enhancing the accuracy of this vital procedure in the diagnosis of diseases. We achieve 65 -95% reduction in specularity on phantom model using the proposed approach.**

I. Introduction

Camera and light based technologies have been widely used in systems for digital pathology, ophthalmology, gynecology, etc. These systems help doctors in patient diagnostics, like,fundoscopic eye examinations, endoscopy, and a variety of intra-cavitary applications such as endoscopy and colposcopy.

Several subtle features like blood vessel patterns, surface irregularities etc are indicative of deviation from normal. For e.g. in colposcopic examination changes like the aceto-white kinetics, punctations, and vascular patterns determine the severity of the cancer. Hence, the precise identification and localization of these subtle features is of critical importance to the diagnostic accuracy of any medical procedure. However, glare is formed due to reflection of light resulting in masking of these tiny features [1]. One of the examples is shown in Figure **1**. These glare spots are the direct result of the unavoidable bright lights reflected by wet, textured, and shiny tissue surface. Figure **2** shows the geometry (based on simple ray tracing) of how a glare spot is formed of a small image region if it is wet or shiny. Here one can see that while the actual dry surface of the tissue/organ is clearly recordable when the reflection is diffused as on the left, the powerful glare from the reflection from the wet surface on the right almost completely masks out the diffused reflections from the actual tissue surface below the water. We have proven our hypotheses using a medical device which has multiple light sources and camera such as a colposcope.

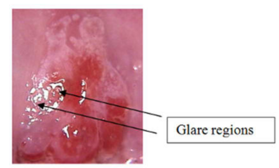

Figure 1: Glare regions in a colposcopy image

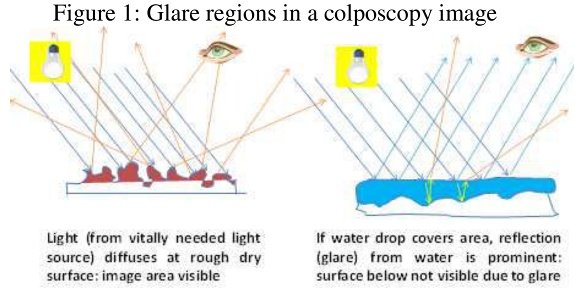

Figure 2: Formation of glare spot due to the presence of reflective surface

There have been few attempts in solving the problem of glare reduction through interpolation and estimation [2] as well as through in-painting techniques [3]. However, these methods cannot reconstruct original information present in the image but can only give an estimate from surroundings. This can lead to missing the features which are only present in glare regions thereby leading to wrong diagnosis.

Static Camera Lighting: The camera lighting used for devices like colposcope, is a set of LEDs fixed to the camera, and therefore the position of the glare-spots on the image does not shift, hence the image information from these spotted regions are irretrievably lost as seen in Figure **1**. All the known techniques [4], [5], [6] from image processing and computer vision as well as white balance settings in some of the medical devices like, the colposcope are incapable of getting rid of these glare regions. Hence, a complete solution to remove glare is not available for this problem. We describe a novel hardware plus software solution that provides dynamic illumination for intelligently removing the glare from the images and ensuring that subtle features are not masked under this specular reflection. In this paper the term image and frame will be used interchangeably.

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II. Materials And Methods

Our method is based on dynamically alternating between multiple LED switching combinations to obtain frame sequence with different/disjoint specularity patterns. These frames are then fused to get the image with minimum specularity. A block diagram of the proposed approach is shown below in Figure 3.

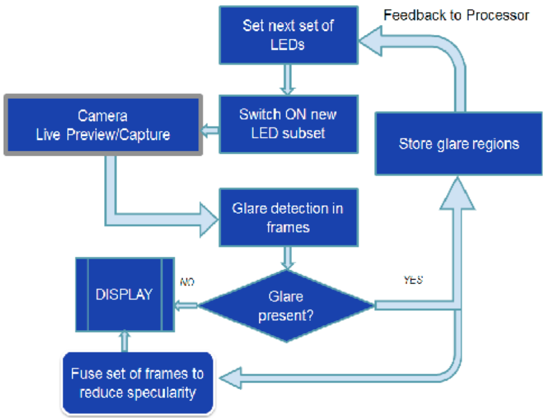
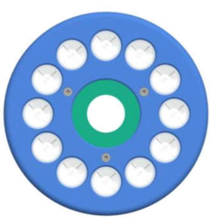


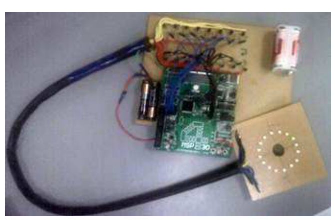
Figure 3: Block diagram of the proposed method

A. Hardware Details

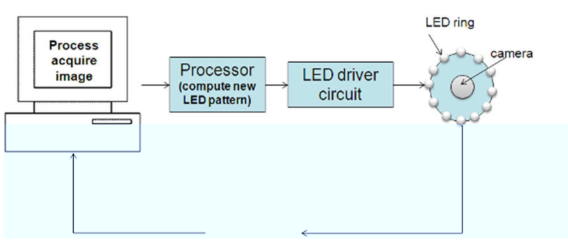
The LEDs are arranged in a single ring format (Figure 4: (a)) around the camera lens to suit a medical device. Each LED is controlled independently through an embedded system processor. Number of LEDs is subject to the illumination power of each LED and the cost factors. Each LED is of sufficiently high power so that just a few of them should be able to illuminate the entire surface for good imaging (even though there may be many of them in the ring, the idea being that this gives great control over the geometry of the lighting and hence on the glare).



(a)



(b)



(c)

Figure 4: (a) LEDs arrange in a circular ring. (b) Figure of the prototype built and (c) corresponding hardware diagram

Figure 4: (b, c) shows the prototype built with the corresponding hardware diagram to independently control the LEDs.

B. LED Switching and Video Acquisition

The complete set of LEDs used for illumination are divided into subgroups and each of this subgroup is switched on at any time, and this subgroup decided in prior based on experimental performance.

For each subset of LEDs switched on, a video frame is acquired from the camera, and the next frame is acquired by turning on a different subset which will cause glare from different spots and which, when fused with the first set, will eliminate the glare spots from the previous frame as well as the current frame. The entire sequence of frames in the full video acquired is then selected and fused in contiguous subsets based on fall time. Say the current LED subset is 'A' in frame i - and the rise time of the fired LED subset 'B' in frame $i+k$ should not cast a bright spot in the same image location in frame $i+k$ where 'A' has already cast a bright spot in frame i. This difference k between the frame numbers for fusion is dependent on the rise and fall time of the LED's.

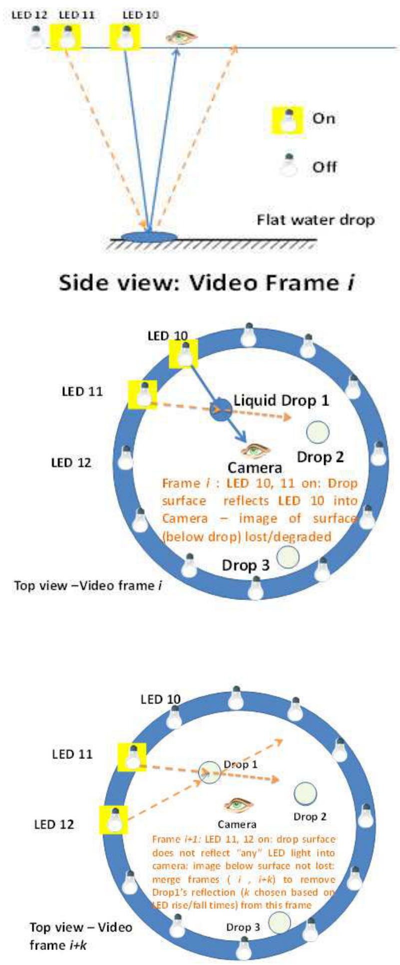


Figure 5: Sequence of LED firings to eliminate glare from at least one of two fused frames

Figure 6 below shows how the specularity changes on an object on changing the LED sequences. The first image shows maximum glare and other images are with different subgroup of LED switched on. Further, maximal illumination on each frame is achieved by keeping those LED's on for longer duration that cause less glare and keeping those LED's on for less duration that cause more glare (because of the dynamic dependence of the glare spots on the shine pattern on the object and on the which LED subgroup was used just before, this can only be done online)

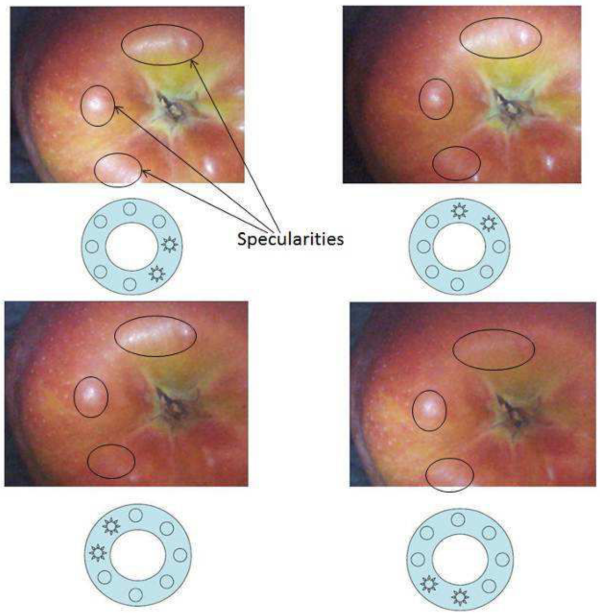


Figure 6: Change in specularity with different LED sequences

C. LED switching patterns

Experiments were performed with different LED switching patterns (Figure 7) programmed to switch and rotate at the video frame acquisition rate. Switching one opposite LED and rotating at the frame rate produces better results. This is a preferred pattern as larger area is illuminated with very small specular regions.

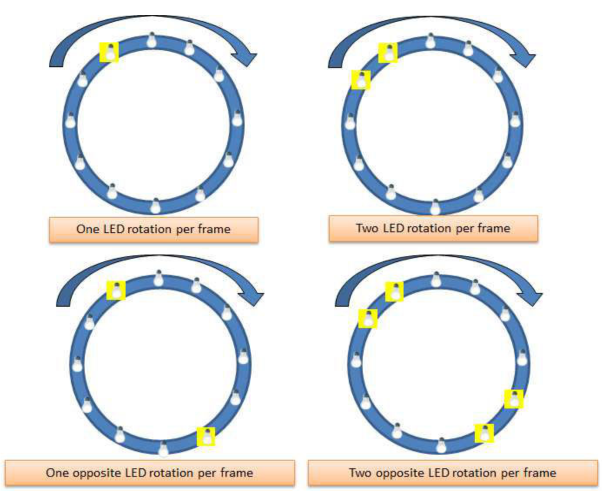


Figure 7: Various LED switching patterns

D. Glare detection and its reduction using image fusion

In order to obtain a glare free image, initially glare regions are automatically identified in the image sequence 'F_{seq}' of about 29 fps obtained after one complete rotation of LED sequence. The camera is static when 'F_{seq}' is acquired. All these images are fused together at the regions where glare is detected. Glare regions are detected as small, saturated, high contrast and white regions. In an image, 'F' in 'F_{seq}' the G component of the RGB color space is used as feature space as it provides good glare to the background ratio in order to identify the glare pixels. The glare pixels are white in color, therefore the G happens to be a good space for the feature detection. A local maximum for histogram generated by G component is identified dynamically. The pixels above this local maximum represent the saturated values. A mask for the glare pixels is then generated and applied on the image 'F' to remove glare pixels from it. The resultant image 'F_G' shows the regions 'G_L' where glare is present. Figure 8 shows the results from intermediate steps.

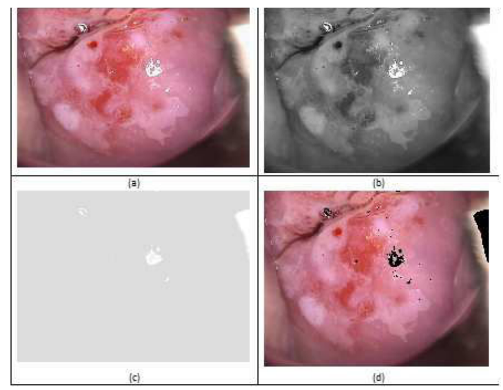


Figure 8: Method for glare detection (a) Original image (b) Green channel (c) Glare detected (d) Glare on the image

The step of glare detection is followed by fusing images at 'G_L'. The image fusion algorithm is developed to reduce the glare from multiple frames 'F_{seq}' taken with different LED patterns. The median algorithm gives best performance retaining the image quality and uniformity after fusion. The median output (see equation 1) is compared with minimum intensity fusion (see equation 2) which results in darker images and hence median is selected. $F(:,:,k)$ is the kth input video frame in 'F_{seq}' and $F1$ is the fused output. We have chosen N=8 in our experiments.

$$\forall(x \in G_L), F1(x) = \text{median}_{k=1:N} F_k(x) \text{ ---(1)}$$

$$\forall(x \in G_L), F1(x) = \min_{k=1:N} F_k(x) \text{---(2)}$$

Using the glare detection and image fusion algorithms on 'F_{seq}' a resultant image is obtained that contains true object information at all times. After fusing the frames acquired with different LED switching patterns in Figure 6, the specularity can be reduced as shown in Figure 9. It can be observed that an image with reduced specularity is obtained.

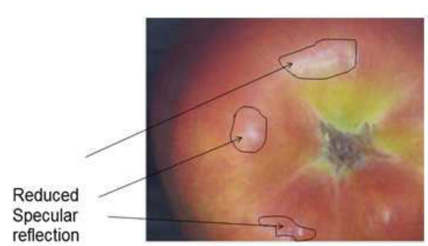


Figure 9: Experimental result of image fusion algorithm for images in Figure 6

Results And Discussions

The dynamic illumination system has been tested on a variety of objects including artificial objects like book, bottle, cervix mannequin model and oral mucosa. As described in last section, different switching patterns are tested to see the specularity removal qualitatively and quantitatively.

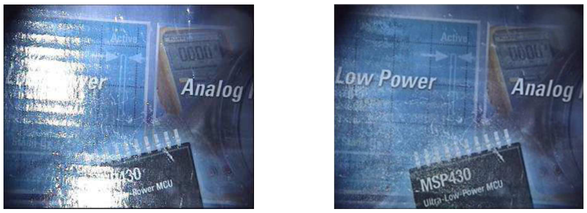


Figure 10: Specularity removed on a book

In Figure 10, the left image shows when all the LEDs are switched on while the right image shows the result of our dynamic illumination system. Earlier some parts of the writing were not visible and after dynamic illumination , it is seen clearly.

Figure 11: Specularity removed on a bottle

In Figure 11, the left image shows when all the LEDs are switched on while the right image shows the result of our dynamic illumination system on a bottle. It is clearly evident that the subtle feathers on the bird is visible in right hand side image as well as letters “IS” are visible using our method.

Experiments were also performed on a cervix mannequin model to mimic the diagnostic procedure. Figure 12 shows the cervix mannequin with oil applied on it to mimic specularity. It has been found that the specularity was reduced by 71% (Percentage of glare pixels in the dynamic illumination image/ Percentage of glare pixels in original image). Figure 13 shows that the specularity was reduced by 95% with associated reduction in brightness. Experiments were also performed on oral cavity. However artefacts were found due to motion (Figure 14). Some of the challenges that were encountered while performing the experiments were proper camera focusing on some objects with dynamic lighting and real time fusion of the images. One drawback observed in this method is that artefacts could be generated if the object is moving.

Figure 12: (a) All LEDs on (b) Dynamic illumination result (Specularity reduced by 71%)

Figure 13: (a) All LEDs on (b) Dynamic illumination result (Specularity reduced by 95%)

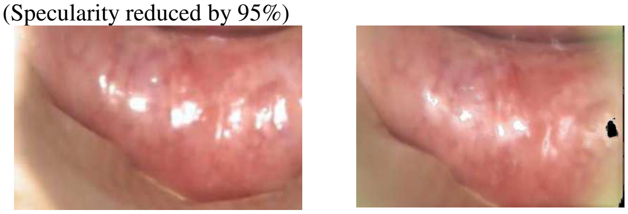


Figure 14: (a) All LEDs on (b) Dynamic illumination result

Conclusions

In this paper we show that specularity could be reduced in a range of 65 – 95 % in medical images using dynamic illumination system without any significant hardware requirements. This would be useful for capturing and archiving glare reduced/ free images for review at later date. In future, we would like to make the system real time and remove the artefacts due to motion so that live preview without glare could be delivered to the user.

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