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A Low-cost Scalable Solution for Digitizing Analog X-rays with Applications to Rural Healthcare

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Abstract— **In this paper, we present a low-cost scalable solution for digitizing analog X-ray images with the goal of improving diagnostics in rural and remote areas, in addition to having potential applications in disaster healthcare. Our solution attempts to capitalize on the rapid gains made in cellular communication and mobile technologies. The proposed mobile application lets the user digitally acquire the analog X-ray image and apply enhancement operations to it. A novel non-linear technique for X-ray image enhancement has been proposed and implemented in the application. Additionally, several standard enhancement techniques have also been implemented. A proof-of-concept of the proposed solution is demonstrated with an Android application running on a smartphone. Results from real-world data collected at a semi-urban hospital in India are presented. The Android application has been made available online at the fifth authors' homepage.**

I. INTRODUCTION

The world's population is projected to reach the 8 billion mark in less than a decade and a half from now. A large fraction of the growth will be seen in developing economies resulting in severe stress on the public health care system. In a country like India, a large percentage of the population would still be rural by 2015 [1]. The rate of population growth is expected to be much higher than the rate of growth health care facilities [2]. This mismatch is going to leave large swathes of population with limited or no access to basic health care. The challenges are very similar in urban and semi-urban areas as well due to population migration.

Low-cost, effective and efficient healthcare solutions are the need of the hour. For the solutions to be meaningful in the setting of a developing economy, the most important requirement is for them to be low-cost. The effectiveness of these solutions is determined by their ability to scale. Good diagnostics play a vital role in making the solutions efficient and is the focus of this work. X-ray images are among the oldest and most widely used diagnostic modality in medical science and are very popular even in the present day and age. While impressive progress has been made in X-ray imaging, the costs associated with the state-of-the art X-ray imaging solutions makes them unviable for widespread deployment. Analog X-rays are the only alternative and continue to be widely used. However, their use reduces the efficiency of the diagnostic process. In order to increase the efficiency of analog X-ray based diagnosis and reduce cost, the role of technology is critical.

In this paper, we propose a low-cost solution for the digitization of analog X-rays using recent technological advances in communications and mobile technologies. It is estimated that India alone has 900 million cellular subscribers and the number exceeds 6 billion worldwide [3]. While a majority of these subscribers use basic handsets, smartphone usage continues to grow very rapidly and has tremendous potential in healthcare applications. This growth has been largely spurred by the Android operating system – a free open-source platform. This has also contributed to smartphones becoming more affordable and thereby reaching ever greater numbers of people on the planet. Further, the advances in cellular communication technologies have resulted in higher data rates becoming available for communication and making existing communication channels much cheaper. Both of these factors have motivated the proposed solution.

The paper is organized as follows. Section II formalizes the problem to be addressed. Section III discusses the proposed solution and IV presents the results. Section V concludes the paper and discusses directions for future work.

II. PROBLEM STATEMENT

Analog X-rays are still overwhelmingly used all over the world. Many a time, the X-rays are seen by a radiologist several days or weeks after it has been taken. The reason for this could range from a shortage of radiologists to poor geographic connectivity. These time delays could potentially be fatal. Digital X-rays offer a good solution in that they could be easily sent over cellular networks to the radiologist and thereby drastically alleviating poor geographic connectivity issues. Additionally, digital X-rays lend themselves very well to further processing such as denoising, contrast enhancement etc. that would aid diagnosis. However, the high cost of digital X-ray machines make them ill-suited for widespread usage in developing economies.

The central problem addressed in this paper is to provide a low-cost and scalable solution for the digitization of analog X-rays. As discussed in section I, keeping costs low is the most important requirement of the solution. Scalability is the

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other important requirement of the solution. A discussion of how both these requirements can be met is presented in the following section.

III. PROPOSED SOLUTION

The most obvious low-cost solution to digitizing analog X-rays is to photograph them using a digital camera. It has been shown that a camera resolution of 5 million pixels is sufficient to accurately digitize analog X-rays [4]. While the use of a dedicated digital camera may solve the digitization issue at a low cost, it does not address the problem of communicating the images.

The features available on a smartphone makes it ideal to solve the problem at hand. Not only is the cost of a smartphone comparable (and rapidly becoming favorable) to a dedicated digital camera, so are its imaging abilities. More importantly, smartphones are essentially communication devices and are able to communicate multimedia content over the cellular network. Finally, the rapid proliferation of smartphones makes the solution a highly scalable one. An android app has been developed to demonstrate the solution. The solution steps are outlined in the following subsections. We assume that X-ray images are represented in gray scale with 8 bits per pixel.

A. Image acquisition

The first step in the solution is image acquisition. Analog X-ray plates are typically viewed over a light box. It was found that setting a laptop or monitor's screen to its maximum brightness and using a white background provides enough lighting to view and digitally acquire the plate. This method is a low cost alternative using existing infrastructure in case access to the tube box is limited. However, this method results in artifacts that can be handled using image processing techniques.

B. Image enhancement

The next step in the solution is the provision of image processing tools to let the user enhance the acquired images. Toward this end we propose a novel non-linear point operation that is designed to improve contrast by amplifying higher image intensities and suppressing lower intensities. An image $I(i,j)$ of size $M \times N$ is transformed to an image $J(i,j)$ of the same size using the following equation.

$$J(i,j) = \text{int}[I(i,j).\frac{I(i,j)}{T}], \quad (1)$$

where T is a variable gain control parameter. This is unlike the well-known point-wise squaring function which generally causes image saturation. The image is first "normalized" by T and the result is multiplied with the original intensities. The normalization generates a weight map that is proportional to the pixel intensity that results in the enhancement of high intensities and diminishes low intensities. In case T exceeds the maximum gray level of the image, information in the low intensity areas get enhanced. When T is less than the maximum gray value in the image, the high intensity areas are enhanced. Further, since it is a point operation, the structural integrity of the image is maintained. This is critical in the context of diagnosis. Additionally, the application also implements several standard enhancement methods including histogram equalization, full scale contrast stretch, log range compression, and edge enhancement using the Sobel operator [5].

C. Android app

An Android app has been developed to demonstrate the proposed solution. While standard Android APIs provide access to the camera and simple image processing operations, OpenCV provides a much richer image processing toolkit [6]. The app uses the OpenCV library to implement the image enhancement techniques discussed in section III-B. The application is designed to do the following:

- launch the camera at the click of a button.
- save the image either locally or on an SD card.
- apply following enhancement methods:
  - Sobel edge detector.
  - histogram flattening.
  - the novel non-linear method discussed in III-B.
  - Log compression.
  - full scale contrast stretch.

The non-linear technique and the log compression technique were implemented using the OpenCV tools. The other enhancement methods directly use the APIs provided by OpenCV. Android was considered in this work since it is a very popular mobile operating system (OS) and is open source software. The app can be easily ported to other mobile OSes since the OpenCV library is available for a majority of popular OSes including iOS and Windows 8. Further, a careful search on the Google Play store showed that while there are several image enhancement apps available, there are none dedicated to X-ray image processing.

IV. RESULTS

The results of each stage of the proposed solutions are discussed in the following.

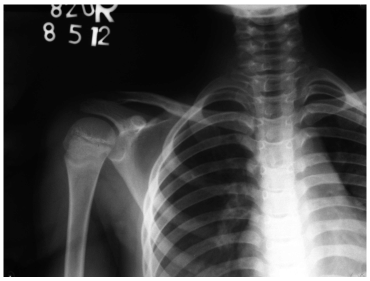
A. Image acquisition

The most critical component of the proposed solution is the digitization of the X-ray plate at an acceptable quality level. To demonstrate that the proposed solution is practically viable, we first compare the images acquired on a mobile device (Sony Xperia U, 5MP, 2592×1944 pixels) with a regular point and shoot camera (Sony Cyber-Shot, 10.1 MP). A smartphone and a digital camera are comparable in price at the time of writing. From Fig. 1, it is clear that the qualities are comparable and validates the proposed approach. This comparison was carried out on 10 X-ray plates with very similar results. Further, the smartphone used is a couple of years old which points to the fact that even lower end smartphones can be used to achieve the proposed solution.

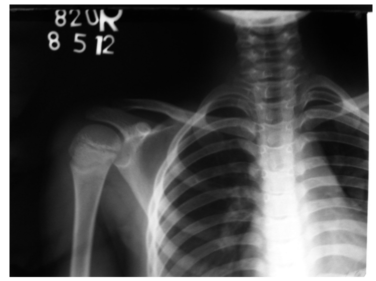
(a) Digital camera.

(b) Mobile camera.

Fig. 1: A comparison of an X-ray plate digitized using a digital camera and a mobile camera.

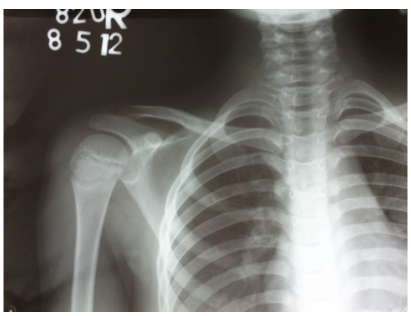


(a) OpenCV.

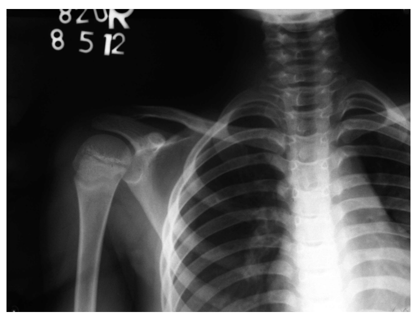


(b) Matlab.

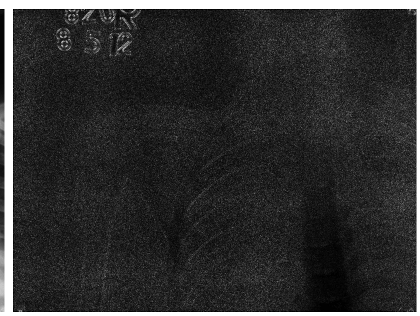
Fig. 2: A comparison of the results from OpenCV and Matlab implementations of (1).



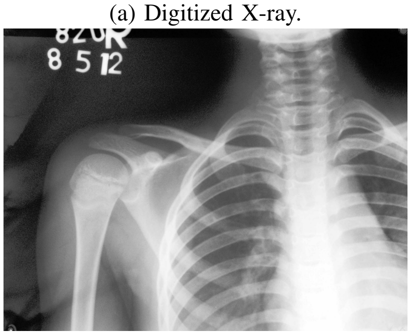
(a) Digitized X-ray.



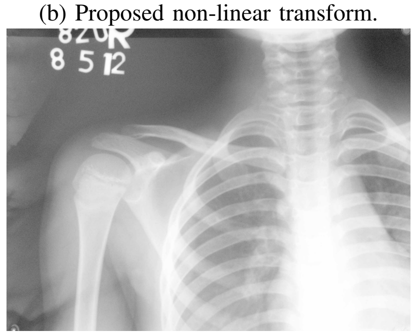
(b) Proposed non-linear transform.



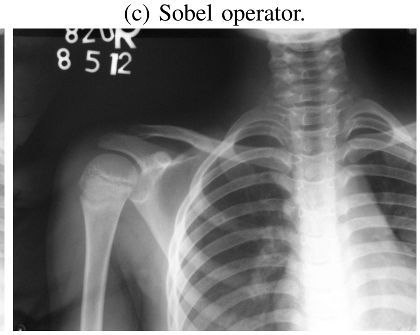
(c) Sobel operator.



(d) Histogram Flattening.



(e) Logarithmic compression.

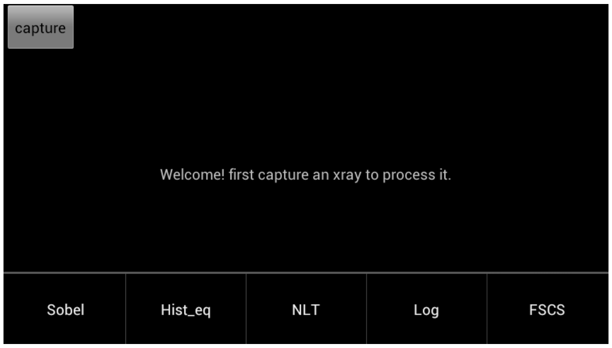


(f) Full Scale Contrast Stretch.

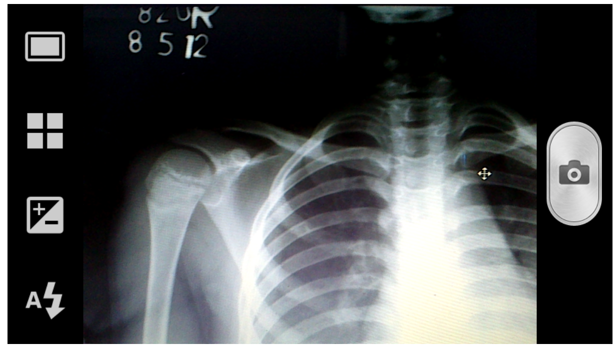
Fig. 3: Results from the Android application.

B. Image enhancement

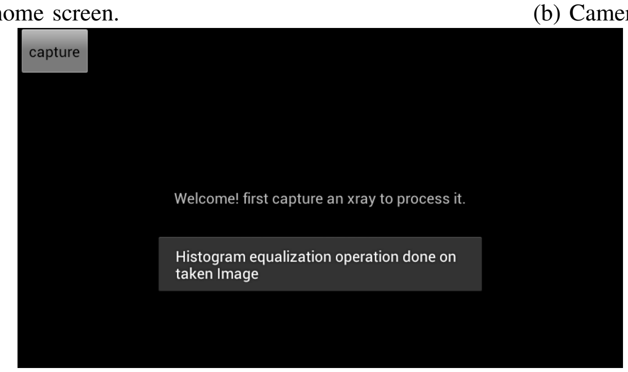
The application implements a number of image enhancement algorithms [5] including the novel algorithm proposed in section III-B. As mentioned previously in section III-C, the algorithms were implemented using the APIs provided by the OpenCV Android library [6]. The non-linear transform was implemented in both Matlab and OpenCV as a sanity check. The closeness of the results shown in Fig. 2 demonstrates the strength of OpenCV as a fast and efficient toolkit. The OpenCV results are shown in Fig. 3. Fig. 3b illustrates the efficacy of the proposed non-linear transform is enhancing the quality of X-ray images. Its simplicity makes it amenable to fast and efficient implementation. Figs. 3c, 3d, 3e, 3f show the respective outputs of applying the Sobel operator, histogram flattening function, log compression operator, and full scale contrast stretching on the reference image in Fig. 3a. These outputs illustrate the usefulness of the proposed solution as an aid for diagnosis.



(a) App home screen.



(b) Camera launch.



(c) Histogram equalization.

Fig. 4: The app UI.

C. Android app

Last but not least, the Android app GUI is shown in Fig. 4. The app components include a button each to launch the camera and to perform various image enhancement operations as mentioned in section III-C. Fig. 4b shows a screenshot of the camera launched from the app and Fig. 4c illustrates the status after histogram equalization is complete. The app has been made available online at the fifth author's home page under the "Research" tab.

We would like to note that the quality of all the image results presented have been validated by a medical practitioner. Further, only a subset of the results have been presented due to a lack of space.

V. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a low cost solution for the digitization of analog X-ray plates with the goal of improving diagnosis at rural and remote health care centers. A novel enhancement technique optimal for X-ray image enhancement was proposed. The solution was demonstrated with an Android application and results were reported using data acquired at a semi-urban hospital. Based on the results, we conclude that a smartphone can prove to be a very useful tool in improving the quality of healthcare at a low cost. The smartphone's camera quality is comparable to a dedicated digital camera. Additionally, its processing abilities can be utilized for image enhancement which can aid in better diagnosis. Also, its communication abilities can be used to reach radiologists who could potentially be located any where in the world. As part of our future work, we plan to integrate this communication ability into the application in addition to developing and implementing more sophisticated enhancement algorithms. As part of our future work, we also plan to understand the effects of mobile phone camera hardware on the quality of results.

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