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Super-resolution of retinal images using multi-kernel SVR for IoT healthcare applications

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HIGHLIGHTS

- An architecture for IoT healthcare is proposed.
- Learning based single image super-resolution for retinal images is proposed.
- Focuses on the processing of retinal images captured using pan optic ophthalmoscope.
- Generates good quality retinal images which helps image analysis.
- Produces better peak signal to noise ratio and mean squared error values.

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ABSTRACT

Internet of Things (IoT) healthcare is one of the most popular areas of research due to the rapid development in information and communication technologies. IoT system focusing on human vision would be an ideal solution for the people in developing countries to have adequate medical attention. This paper proposes a hybrid architecture for IoT healthcare to process the retinal images captured using smartphone fundoscopy. The proposed super-resolution (SR) algorithm for retinal images use multi-kernel support vector regression (SVR) to improve the quality of the captured images. The experimental results with respect to the peak-signal-to-noise ratio (PSNR) and mean squared error (MSE) show that the proposed super-resolution approach for retinal images performs better when compared to the state-of-art algorithms. Further, the hybrid architecture helps the ophthalmologists in efficient diagnosis by providing high resolution retinal images.

1. Introduction

IoT has taken world of research to a new level by its vast areas of application. One of the main applications of IoT is IoT-healthcare. The revolution, triggered by IoT is redefining health care with promising technological, economic, and social prospects [1,2]. The concepts of IoT when used for healthcare applications provide an effective communication between the patients and the physicians. Monitoring the physiological parameters of patient's remotely is effectively achieved by IoT healthcare [3]. The geolocation of patients help the practitioners to monitor the patients. Apart from providing diagnosis, the IoT healthcare system provides solutions as well [4–6]. Wearable computing devices take remote health monitoring to its newest height by requiring minimal to no human intervention.

Teleophthalmology is an example of telemedicine which focuses on the ailments and treatments related to human vision. Vision impairment is a major and avoidable public health problem worldwide. According to the latest studies held in developing countries 53.5% of people of rural population never had an eye examination [7,8]. 36% of the examined population were diagnosed with eye complications [9]. The survey by Fakir M. Amirul Islam et al., [10] indicated that 29.1% of the tested population was having visual impairments. The major reason was the lack of affordability and awareness. Teleophthalmology helps these kind of people by enabling them to get adequate access to the specialists without needing to travel far from their localities.

Fundus ophthalmoscopy (fundoscopy) is an important part of ophthalmology that forms the base for the treatment by providing photo documentation of intraocular pathologies, diagnosis and sharing of information with physicians and patients. The acquisition of high-quality fundus image requires a combination of appropriate optic lens and coaxial light source. Traditional fundus cameras have difficulties with convenience, compatibility and portability. On the other hand, smartphone fundoscopy uses smartphones

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Fig. 1. Welch Allyn iExaminer system.

which are readily available, relatively cost effective, easy to operate and compatible across various platforms and systems, making them ideal for use in remote areas. There are several smartphone based ophthalmological applications available across various platforms [11]. The Welch Allyn iExaminer system, depicted in Fig. 1 is one such ophthalmological application which enables an iPhone to operate like a pan optic ophthalmoscope [12,13]. The retinal images that are captured using smartphone fundoscopy are low quality images that show a smaller field of view, lower resolution, and poorer contrast due to the hardware limitations [14]. The studies in literature on smartphone fundoscopy suggest that the limitations of the technique and its applications lie in the image quality. The classic solution for addressing this issue is to develop an image super-resolution algorithm. The super-resolution of medical images improves the quality of analysis and helps effective diagnosis. Thus an image processing technique that improves the quality of the retinal images captured by the smartphone fundoscopy is needed [15].

This paper proposes a learning based single image super-resolution approach for retinal images in order to improve the quality of the fundus images that are captured using smartphones. The major advantage of SR approach is that, SR algorithms are device independent. This paper also proposes an architecture of IoT healthcare focusing on the processing of retinal healthcare images.

This article is organized as follows. Section 2 gives the information about the various existing super-resolution approaches. Section 3 has the proposed architecture and the super-resolution approach. The experimental results and performance evaluation are given in Section 4. Section 5 gives the conclusions and future enhancements.

2. Related works

Image super-resolution is the process of generating high resolution images from a single or a set of low resolution images. It has vast areas of applications such as satellite imaging, video surveillance and medical image analysis [16]. The major classifications of super-resolution algorithms are single image SR and multi-frame SR. Single image SR needs just a solitary low resolution input whereas multi-frame SR needs more than a single input low resolution image. In the sensitive application areas like medical image analysis, it is not always practical to apply multi-frame SR. So an elaborated study has been carried out on various single image super-resolution algorithms. The single image SR algorithms are classified as reconstruction based SR and learning based SR. The reconstruction based algorithms focus on removing the aliasing artifacts from the low resolution input images. These reconstruction based algorithms fail to produce good quality outcomes when the magnification factor is over 2 and suffer from the lack of well-defined boundaries. Whereas the learning based algorithms learn and formulate the relationships among the low resolution and high resolution image pairs [17].

In order to perform learning, a collection of images known as learning dictionary is used. The learning dictionary is selected based on the application in which the SR approach is used. On the other hand, the learning based algorithms that use the input low resolution image as the only source for learning, do not require any learning dictionaries. Thus the learning dictionary does not have a fixed size. Various techniques have been employed by the researchers to achieve better learning outcomes. The sparse representation of images for learning is used for image super-resolution. However, it requires an additional refinement process [18,19]. The approaches which use support vector machine (SVM) and its regression minimize the reconstruction error considerably. The application of SVR along with sparse coding technique produce commendable improvement in the quality of the output SR images in terms of PSNR [20–23]. The neural networks (NN) based learning has also been used in the area of image super-resolution. Several researchers have attempted to enhance the image super-resolution process by NN based learning. As stated in [24] Hopfield NN produces super-resolution outputs from remotely sensed images. A hybrid of Probabilistic neural network and the Multi-layer perceptron makes the image SR faster [25,26]. The optical character recognition (OCR) applications require the images to be of good quality. Image SR is used in OCR to enhance the inputs. The usage of soft learning prior along with OCR enabled better recognition of license plates [27]. Similarly the recognition of handwritten characters requires the application of SR. The back propagation networks are effectively used in the recognition of handwritten zip codes [28]. The application of CNN produces better approximation during learning and the reconstruction of high resolution outputs [29,30]. The deep convolutional networks with rectified linear unit (ReLU) as the activation function produce good quality outcomes [31,32]. However these NN based approaches need a predefined learning dictionary and make certain assumptions about the contexts under which the low and high resolution training data is built. This training data is used to encode the overlapping low resolution input sub-images.

This paper proposes a learning based single image super resolution algorithm which applies the advantages of support vector regression for learning and probability theory in order to minimize the errors during reconstruction. Further, the proposed approach learns itself and develops a nonlinear functional mapping between low and high resolution retinal images which results in minimum super-resolution reconstruction error.

3. Proposed IoT healthcare architecture with retinal image super-resolution

The proposed architecture for IoT healthcare application focusing on human vision is depicted in Fig. 2. Each block in the proposed architecture takes care of a well-defined task.

The various blocks in the architecture are,

- *Retinal image capturing* —The retinal images of patients are captured using pan optic ophthalmoscope. The captured retinal images will be transmitted to the cloud backbone for subsequent processing.
- *Retinal Image super-resolution* —Retinal image SR block takes care of the generation of high resolution retinal images from the images captured at the patient's end.
- *Eye disorder classification* —The responsibility of this eye disorder classification block is to classify the incoming retinal images into various categories based on their properties and structure. The outcome of this block is the disease classification. This block will contain a well-defined repository of retinal images.

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