Image Compression and Resizing for Retinal Implant in Bionic Eye

N.Sharmili
Dept of CSE
GVP College of Engineering
Vishakhapatnam, India.
logintosharmi@gmail.com

P.S. Ramaiah
Dept of CS and Systems Engg.
Andhra University
Vishakhapatnam, India
psrama@gmail.com

G.Swamynadhan
Dept of CSE
GVP College of Engineering
Vishakapatnam, India
swamy.nadhan541@gmail.com

Abstract

One field where computer-related Image processing technology shows great promise for the future is bionic implants such as Cochlear implants, Retinal implants etc.. Retinal implants are being developed around the world in hopes of restoring useful vision for patients suffering from certain types of diseases like Age-related Macular Degeneration (AMD) and Retinitis Pigmentosa (RP). In these diseases the photoreceptor cells slowly degenerated, leading to blindness. However, many of the inner retinal neurons that transmit signals from the photoreceptors to the brain are preserved to a large extent for a prolonged period of time. The Retinal Prosthesis aims to provide partial vision by electrically activating the remaining cells of the retina. The Epi retinal prosthesis system is composed of two units, extra ocular unit and intraocular implant. The two units are connected by a telemetric inductive link. The Extraocular unit consists of a CCD camera, an image processor, an encoder, and a transmitter built on the eyeglass. High-resolution image from a CCD camera is reduced to lower resolution matching the array of electrodes by image processor, which is then encoded into bit stream. Each electrode in an implant corresponds to one pixel in an image. The bit stream is modulated on a 22 MHz carrier and then transmitted wirelessly to the inside implant. This paper mainly discusses two approaches in image processing which reduces the size of the image without loss of the object detection rate to that of the original image. One is about the related image processing algorithms include image resizing, color erasing, edge enhancement and edge detection. Second one is to generate the saliency map for an image.

Keywords- *Epiretinal implant, AMD, RP, Extraocular and Intraocular*

I. INTRODUCTION

Retinal Implant is a prosthetic device that maps visual images to control signals, based on which it stimulates the surviving retinal circuitry. Image compression for bionic eye compresses and resizes the images preserving the object detection rate of the image. The resized image obtained has a comparable object detection rate to that of original image. This indeed reduces the processing over head on implant inside the body. In eye the visual information from the retina's 130 million photoreceptors is compressed into electrical signals carried by 1.2 million highly specialized ganglion neurons, whose axons form the optic nerve. The optic nerve transmits visual information via the lateral geniculate nucleus to the primary visual cortex of the brain. Blindness can result when any step of the optical pathway sustains damage.

One possible avenue that has been explored is to use implantable microelectronics. There are three logical placements of the device 1) The retina, which can be further divided into epi-retinal and sub-retinal [1]. The epi-retinal referring to the side that faces the vitreous and the

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sub-retinal to the side that is adjacent to the choroid. 2) The visual cortex and 3) the optic nerve. Most of the research groups works on Epiretinal Stimulator compared to others due to having various advantages. Here we will mainly discuss Epi retinal approach [2].

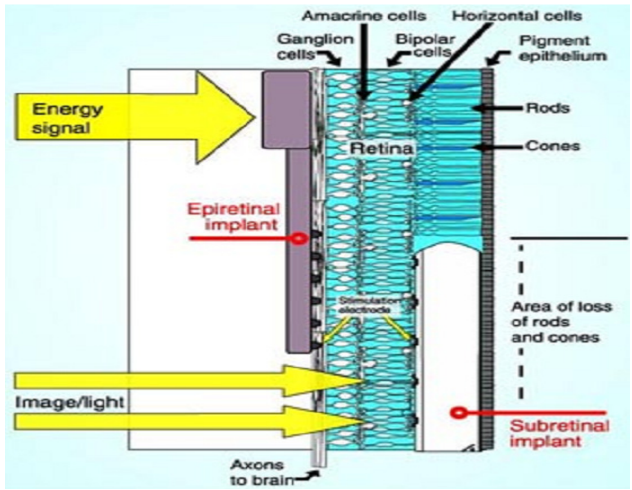

Fig 1: Position of retinal implants inside the eye

II. EPIRETINAL APPROACH

An Epiretinal prosthesis system usually employs a multi electrode array implanted on the surface of the inner retina between the vitreous and internal limiting membrane. Epiretinal prosthesis pass signal to the ganglion cells, while Subretinal prosthesis relay signals to the bipolar cells. A data acquisition system located outside of the body captures images from the surroundings, and converts the information into patterns of electrical signals. Upon the reception of signals through data transmission and processing systems, the electrodes stimulate the remaining retinal ganglion cells and restore vision[2]. Epiretinal approach is easier from surgical point of view but mechanical anchoring of the implant to the epiretinal surface is difficult.

The advantages of the epiretinal approach include the following:

1) A minimal amount of microelectronics can be incorporated into the implantable portion of the device—the wearable portion of electronics allows for easy upgrades without requiring subsequent surgery.

2) The Epiretinal placement allows for the vitreous to act as a sink for heat dissipation from the microelectronic device.

3) The electronics give the user and the doctor full control over the image processing, thus allowing the implant to be customized for each patient.

The disadvantages to this approach include the requirement of techniques that will provide prolonged attachment of the device to the inner retina, and the stimulation at the output of the retina (ganglion cells), which will require more sophisticated image processing to account for retina algorithms.

III. METHODOLOGY

Retinal implant is a prosthetic device that maps visual images to control signals, based on which it stimulates the surviving retinal circuitry. The epiretinal prosthesis system is composed of two units, one extraocular and one intraocular [3]. The two units are connected by a telemetric inductive link, allowing the intraocular unit to derive both power and a data signal from the extraocular unit.

The extraocular unit includes a video camera and video processing board, a telemetry protocol encoder chip, and an RF amplifier and primary coil. The intraocular unit consists of a secondary coil, a rectifier and regulator, a retinal stimulator with a telemetry protocol decoder and stimulus signal generator, and an electrode array.

At the extraocular unit side, a digital camera captures the image which is then preprocessed as defined in sec(IV). The data is further processed by a pulse width modulation circuit (PWM) and subsequently modulated onto an RF carrier using amplitude shift keying (ASK).

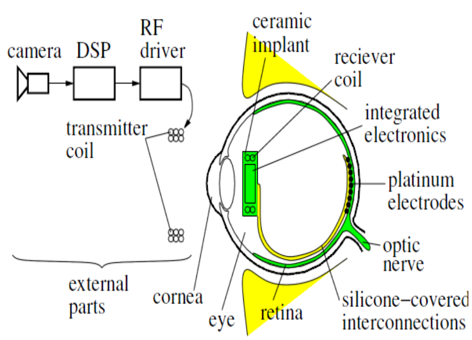

Fig. 2 Bionic eye, comprised of an intra-ocular epiretinal neuro-stimulator (implant) and external support electronics mounted on a pair of spectacles.

The symbol is encoded as a pulse width modulated signal, a 50-50% duty cycle encodes a 0 and 30-70% duty cycle encodes a 1.The modulated carrier is then inductively transmitted to the intraocular unit[11].

The transmitters generate radio frequency electromagnetic fields containing both energy and the encoded image data for the implant. The device requires a wireless data link to provide captured image data to stimulate ganglion cells via electrodes array. In intraocular unit the ASK demodulator receives the power-carrier envelope from the rectifier output and generates the digital PWM signal for the clock and data recovery block. Data and clock signals are then recovered by a delay-locked loop (DLL) and a decoder circuit. After decoding the image information the timing generator circuit is programmed to produce the timing of the stimulus waveforms, including the anodic/cathodic pulse widths, the interphase delay, and the biphasic pulse period [3],[4]. The current control circuit specifies the full-scale amplitude of biphasic current pulses. The biphasic current waveform could be either an anodic pulse first followed by a cathodic pulse or vice versa only if an equal amount of charge is provided by both anodic and cathodic pulses in order to obtain a balanced charge [5]. These pulses will stimulate the electrodes which are present on the implant to perceive the visual information by the patient.

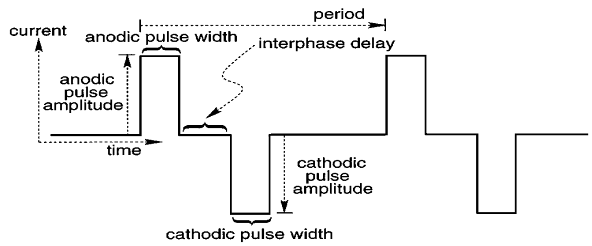

Fig. 3. Electrode current stimulus waveform.

IV. IMAGE PROCESSING IN EXTRAOCULAR PART

The current camera captures images having a resolution of 480x640 at a rate of 30 frames/sec.

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The image processing on these frames consists of edge detection, edge enhancement, decimation and low-pass filtering [6]. The decimated output image will be a 32 x 32 image thus decimating the original image by a factor of 7.5 x 10[7],[8].

Sampling is the selection of suitable samples for analysis of an image. Here, down sampling is used for compressing the image. Then Image filtering is done to remove noise, sharpens contrast, or highlight contours in the captured images. To form the noise free image , the converted gray scale image is filtered by an averaging filter (low pass filter), which is defined as:

$$\frac{1}{25}\begin{pmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

Averaging Filter Mask [10]

Edge enhancement algorithm sharpens the edges in the image frame before decimating the image in order to preserve more edges. Edge Enhancement is done using Laplacian filter mask to highlight the areas with intensity changes rapidly. The edge image obtained using the following edge detection algorithm is scaled and added to the original image to enhance the edges (i.e. convolution on original and filtered images). Here a very sensitive edge detection algorithm is taken which gives the better results than Sobel's and Canny's Edge detection algorithms. The algorithm is as follows:

1. Get the negative value of the second derivative of the current pixel.
2. Remove the center pixel value.
3. Subtract the four diagonal pixels values.

The operator equation is as follows:

$$\mathbf{F(x,y) = -\Delta 2\ f(x,y) - 4f(x,y) - f(x-1,y-1) - f(x-1,y+1) - f(x+1,y-1) - f(x+1,y+1)}$$

The following operator mask represents the above equation:

$$\begin{pmatrix} -1 & 1 & -1 \\ 1 & 0 & 1 \\ -1 & 1 & -1 \end{pmatrix}$$

Adding diagonal values and remove the center value gives us the necessary balancing for edge detection and removes undesired noise. The operator employs the differences between neighboring pixels with respect to the current pixel to become the new value of the current center pixel. The operator removes undesired data (colors and noise) and only holds the edges. The simplicity of the algorithm makes it possible to be implemented by hardware which is suitable for high resolution and large size images.

Then decimation is the next stage. Decimation is a two-step process, which essentially consists of Filtering and Down Sampling. Decimation reduces the noise in the image followed by the reduction in the size of the image. Here the same filter (average filter) is used to which we have used in the previous step to reduce the noise from the image. The filter is implemented only on the sampled image but not on the edge detected image. The sampled is smoothened by this filter and it can be allowed to be used for further stages. So, this image is forwarded for downsampling. In the last stage the edge detected image and Down sampled images must be convoluted very accurately to get the best result else it will lead to corrupted image. So at most care should be taken in bringing both the images in proportion

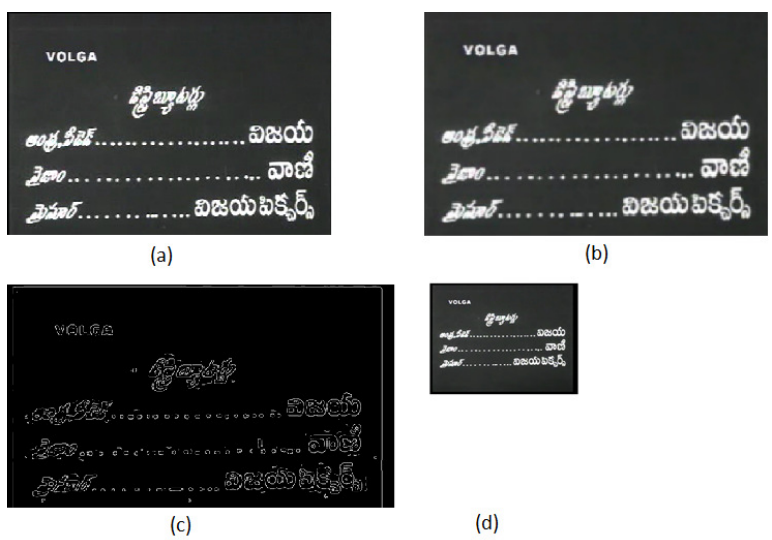

Fig 4.(a) original image (b)filtered image

(c) edge detected image (d) downsampled image

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Saliency maps are mainly used to get the salient parts of the image which will helpful for object recognition in bionic eye[9]. So by using this method blind patients can have partial visibility of the image. For generation of saliency map, first we have to generate image pyramids. The image pyramid is a data structure designed to support efficient scaled convolution through reduced image representation. It consists of a sequence of copies of an original image in which both sample density and resolution are decreased in regular steps. This approach uses three information streams: color saturation, intensity and edge information. These information streams are extracted by converting the input image from the RGB color space to the HSI (hue–saturation–intensity) color space. Gaussian pyramids are created for the saturation (S),intensity (I) and edge (E) information by successively low pass filtering and down sampling by a factor of 2.

Fig 5. Generation of Guassian pyramid with a reduction factor 2

Edge pyramids are created from the intensity stream based on Laplacian pyramid generation. For each level of the pyramid, the edge pyramid image is created as a point-by-point subtraction between the intensity image at that level and the interpolated intensity image from the next level. Center–surround mechanisms observed in the visual receptive fields of the primate retina are then implemented computationally to create feature maps for each information stream. Center–surround interactions are modeled as the difference between the coarse and fine scales of the pyramids. Feature maps are created from only four scales with the center scales ‘c’ at levels (3, 4) and surround scales ‘s’ at levels (6, 7) where the original image is at level 0 of the pyramid[13]. For $c \in \{3, 4\}$ and $s = c + \delta$ where $\delta \in \{3, 4\}$ and $s < 8$, a set of three feature maps is created for each stream. Point-by-point subtraction between the values of the pyramids at the finer and coarser scales is carried out after interpolating the coarser scale to the finer scale using bilinear interpolation. Absolute values of the subtraction are calculated for the saturation and intensity streams and all feature-maps are decimated by dropping the appropriate number of pixels to be 1/16th the size of the original image:

$$S(c, s) = |S(c) - S(s)| \qquad (1)$$

$$I(c, s) = |I(c) - I(s)| \qquad (2)$$

$$E(c, s) = E(c) - E(s). \qquad (3)$$

A linear summation across these feature maps for the different information streams forms the conspicuity maps— Sc for color saturation, Ic for intensity and Ec for edge information[9]. The conspicuity maps undergo normalization referred to by the operator N in the equations. Normalization is an iterative process that promotes maps with a small number of peaks with strong activity and suppresses maps with many peaks of similar activity. Each conspicuity map is first normalized to a fixed range between 0 and 1. Thereafter, a two- dimensional difference of Gaussian filter (DoG) is convolved with the map iteratively. The output is summed with the original map and negative values are set to zero. The DoG filter results in the excitation of each pixel with inhibition from neighboring pixels. The DoG filter function is calculated as stated below:

Intensity and saturation conspicuity maps use three normalization iterations, and edge conspicuity maps use one normalization iteration. The number of iterations for normalization is chosen based on the computational load and pilot studies that examined different iterations of normalization and their effects on the maps. The three normalized conspicuity maps are linearly summed and their average forms the final salience map which again undergoes three-iteration normalization. The region around the pixel with the highest gray scale value in the final salience map signifies the most salient region:

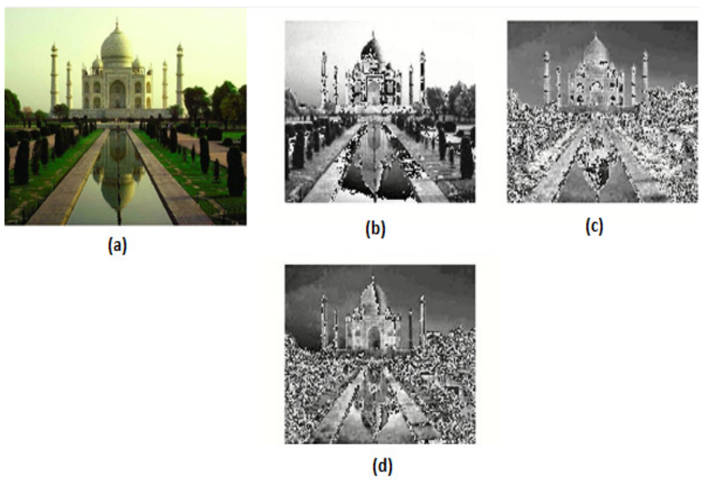

Fig 6. a) The original image b) intensity conspicuity map

c) saturation conspicuity map d) saliency map:

Ultimately the final output image is of 32x32 dimensions in order to stimulate the 32x32 grid of electrodes. This 32x32 image is applied for binarization (by thresholding techniques) to generate the digital data. Now the digital data is encoded as a pulse width modulated signal.

V. CONCLUSION

This paper discusses about the retinal implant architecture and extraocular image processing of epiretinal prosthesis . To be able to meet the real-time requirements of a retinal prosthesis system while running high-sophisticated image processing algorithms, some strategies for transforming high resolution image to low resolution image, image edge enhancement and detection algorithms have been presented. The image processing part in this paper is mainly simulated in matlab and java. In future this work has to implement on suitable DSP processor. The implant requirements have been outlined and the circuit design is explained in detail. A major emphasis has been laid on the design for intraocular part —this makes the stimulator ready for production and implantation.

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