Image Processing and Still Image Transferring for Optogenetics Visual Cortical Stimulator

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Abstract: One of the most effective treatment methods of human disorder is medical implant devices (MID). Today, the MID is very common for solving what clinically is impossible. Among these MIDs, the visual cortical prosthesis (VCP) is an example of the procedures used to restore blind people's vision. The visual cortex stimulator (VCS) typically requires fast data transmission and an efficient power supply. Furthermore, the data processing system has very particular requirements such as low efficient processing, power consumption, and small size. In this paper, image processing has been presented for the VCP. The image simplification procedures are applied using cartoonization, TRON and Edge Enhancement, image compression, and pulse modulation. The Bluetooth low energy used for delivering live simplified images. Image sizes of 64x64 are compressed 86%, testing and implementing different approaches. For stimulating brain cells, the retrieving frames are converted to intensity levels with a rate of 0 to 255 levels.

Keywords: Visual Cortical Prosthesis, Image Processing, Image Simplification

1. Introduction

The human nervous system can be damaged because of disease or trauma, causing conditions, for example, Parkinson's disease. As a primary method of treatment, most of the people try pharmaceutical. However, for a visual disorder, drug cannot restore some cases. Alternatively, electronic neural prostheses can successfully treat this impairment. A retinal prosthesis is an example of that for restoring sight, but it is not efficient and only people with retinal Pigmentosa benefit from it (Degenaar et al., 2009).

Electrical or optical stimulation can be achieved for stimulating the nervous system. Later, for the optical stimulation, the nerves need to be rendered light sensitive via genetic means "Optogenetics" (Drakakis et al 2006). For delivering light to the targeted tissue, high radiance photonic devices are then required (Thompson, Stoddart, & Jansen 2014). Such optical approaches hold the potential to be more effective while causing less harm to the brain tissue.

Today for restoring sight for blindness, eye implant visual prosthesis and brain implant visual cortical prosthesis are widely used (Gaillet et al., 2019). Stimulators have a great role in delivering images from outside world to the neighbour nerve systems in both eyes and visual cortical prosthesis.

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Delivered images require some special processing which is like the natural image processing that inherent in eyes and visual cortex. Image processing for retina is less challenging than the image processing for the cortical stimulators (Soltan et al., 2018).

The visual processing starts with the receptive layer within the back of the eye of the retina. Light enters the eye and goes via the layers of retina cells before entering the receptors at the back of the retina. The light activates the photoreceptors that modulate bipolar cell activity (Filo, Mandić, & Poljičak 2016). Those, in effect, interact with the cells on the front of the retina of the ganglion. The ganglion cell axons are the optic nerve that brings information to the brain. Two other types of neurons are mainly horizontal and amacrine cells (Fattah et al., 2015). The information provided to the brain by the retina does not have equal weight for all parts of the visual scene, but rather highlights visual scene features such as boundary edges that communicate the most important information.

In this work, focusing is on the image processing for brain implant visual cortical stimulator. Images were simplified using Cartoonization, TRON and Edge enhancement (Soltan et al., 2018). Images are compressed to be ready for delivering via the Bluetooth low energy. For image compression, different algorithms are tested for 64x64 pixel images. The discrete cosine transform (Purves et al., 2012) was used for image compression and encryption. The achievement was % 86 of compressions and 25 frames per second are transferred over the Bluetooth Low Energy successfully. Finally, frames are converted to intensity levels with a rate of 0 to 255 levels.

The decompression algorithm and the PWM were written in c language. All results, measurements and tests were conducted on the ARM microcontroller (MK64FN1M0VLL12). A further practical step related to fabrication was taken by manufacturing six layers of round shape of PCB using Altium 16.0 software as shown in Figure 1. The diameter and the thickness of this PCB were 30 mm and 2.68 mm, respectively.

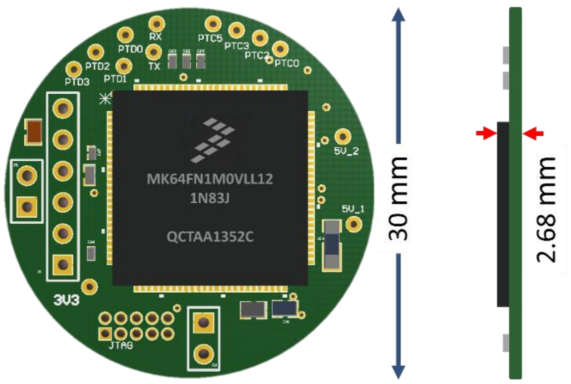

Figure 1: Illustrates the PCB layout using Altium designer 16.1. The diameter of the board is 30 mm, the width is 2.68 mm, and the weight is less than 3g

2. The Arts of Image Simplification

The main goal of visual implant devices image processing is to turn captured video into a stimulating pattern. In addition, a feature to facilitate prosthetic vision could also be introduced by the image processing system. It is understood that a retina is not only a mere photoreceptor but also has a significant role in the processing of images (Ahmed, Natarajan, & Rao 1974). Since the neurons are in a separate layer in the retina (Atick & Redlich 1992), significant steps in retinal-related image processing are aimed at emulating retinal layer functionality.

The retinal processing generally consists of translating to:

- The greyscale levels
- Image simplification
- Zooming
- Edge enhancement

Image simplification is accomplished primarily through reducing unnecessary image detail (Liu et al., 2005); it begins by suppressing low texture, managed by a microcontroller or a minicomputer. Another task of the processing of images is to reduce the size before transmitting the processed data (Margalit et al., 2002). This allows wireless communication to perform its functions easily and efficiently, while encoding algorithms compress the data. The data in the implant system should, therefore, be decoded in the original information (Schwiebert et al., 2001). It is necessary to compress data before sending when the baud rate is limited.

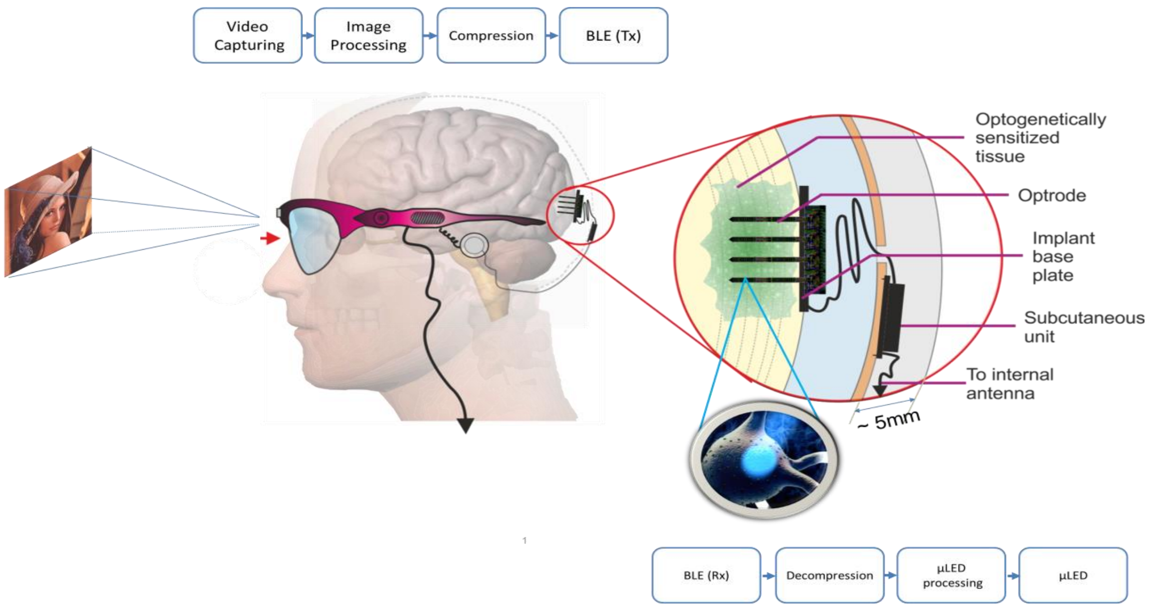

Figure 2: (TOP) General schematic diagram for the wireless microsystem implant for stimulating cortical neurons for restoring sight. The data and power transferred wirelessly to the implant device. (BOTTOM) Block diagram of the implanted VCS device. The data received by Bluetooth and send to the ARM M4F microcontroller. The processed data then send to CMOS µLED for stimulating the brain cells

The information should also be decompressed and the implanted side data collected is used to stimulate the cells of the visual neuron. In this case, an even power distributor algorithm is required to prevent an increase in power (Yaman & Degenaar 2013). This can occur if information is sent over a very short period to the Micro Light-Emitting Diode (µLED). In addition, once transmitted to µLED, the information is encoded to a particular pulse mode code.

3. Method

For testing and developing the external device on Raspberry pi microcontroller, Matlab Simulink, C language and Linux commands were used. The processing of images in the external sections is as follows:

- Still images were captured by the camera with image size 160x120 pixels.
- Image resized to 64x64 pixels
- Use TRON techniques for image simplification.
- Images were compressed using Discrete Cosine Transform (DCT) as shown in Figure 2.
- Images were encrypted.
- Bluetooth is use for image transmission.

The images are obtained via the Bluetooth in the internal parts. The processing of images was as follows:

- Images first decrypted.
- Image decompressed using Inverse Discrete Cosine Transform (IDCT).
- Micro Light Emitted Diode was used for displaying the result (μLED).

Programs for controlling the implanted device are written in C language.

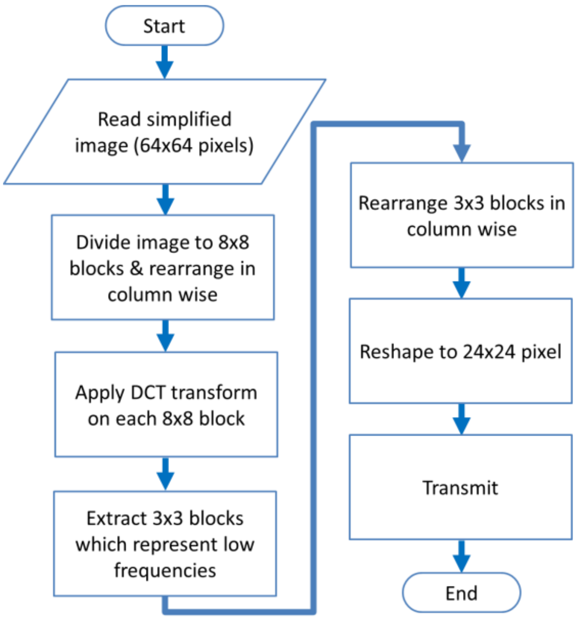

Figure 3: Flowchart for DCT compression algorithm

The concept behind techniques for simplifying the image is to enhance image contrast. Chromatic data is currently not feasible due to the low resolutions of current retina prothesis tools, although this may change. Therefore, we concentrate on the gray-scale picture information content. Because the stimulating array's effective resolution is quite low, it is easier to present more simplistic objects, making it more reasonable to present simple segmented edge weighted objects / scenes.

First, it is important to simplify the images by removing textures of low importance. Anisotropic smoothing is used to achieve this. Iteratively, this algorithm extracts noise and of low importance textures. Like Gaussian blurring, it eliminates the diffusivity with a greater likelihood of being an edge at those positions, i.e., it does not blur them. The process is defined in mathematical terms as follows:

$$I(x,y)^{n+1} = I(x,y)^{n} + \Delta t[(C.\nabla I(x,y)_{H}) + \nabla(C.I(x,y)_{V}) + \nabla(C.\nabla I(x,y)_{D1}) + \nabla(C.\nabla I(x,y)_{D2})] \quad [1]$$

Where I is the original unprocessed image pixel value, ∇ is the gradient operator, and C is the diffusion coefficient. n is the iteration number, Δt is the time step which controls the accuracy and speed of smoothing, and ∇I_H and, ∇I_V , ∇I_{D1} , and ∇I_{D2} represent the horizontal (H), vertical (V), and two diagonal (D) gradients of the image pixel. The simplification process remains ongoing until the following formula is met:

$$D = \sum_{k=1}^{n} a_k - PT \quad [2]$$

Where D is the energy deficit in an image, a_k is the intensity of k^{th} led, P is the power budget (number of LEDs in ON state at the same time) and T is the frame time. As can be seen from (eq 2), if D is positive, it will need further simplification if the picture does not fit into the energy budget.

As with many other detailed algorithms for image processing, optimum parameters differ with user preferences. The key parameters for anisotropic diffusion are the number of iterations n. Smaller n results in further textures remaining; larger n results in even more smoothing, which effectively often eliminates larger edge components, i.e., the picture is blurred. Nevertheless, eventually increasing n will improve the energy deficiency of the object, so this process is regulated by two equations.

Upon completing the anisotropic simplification, we remove the image's spatio-temporal gradients:

$$\nabla I(x,y) = \sqrt{(\nabla_H I(x,y)_S)^2 + (\nabla_V I(x,y)_S)^2} \quad [3]$$

I_S is the simplified image. We simply use the spatial derivatives for still images. To increase edge thickness and eliminate any discontinuity in the gradient image, we convert it to a Gaussian filter and normalize it from 0 to 1. We then define two threshold values, τ_{min} , τ_{max} and set all pixels of the standardized gradient image below τ_{min} to 0 and all the pixels above τ_{max} are set to 1 depending on how much denser the edges need to be.

To generate an edge-weighted image, we define a threshold value K below which all pixels in the standard gradient image are raised to K. K's value defines how much of the image's background information needs to be retained, and this can be calculated by patient choice. The gradient image then becomes a weighting matrix W that will decide how much information will be allocated for the visible images, while also increasing the brightness of the relevant edges. The edge-weighted image would then be defined by the anisotropically simplified image as W multiplication:

$$Edge\ weighted = W * I^{n+1} \quad [4]$$

For this purpose, Raspberry Pi Zero has been programmed and deployed with Matlab Simulink. Matlab function code is presented in Al-Atabany's missing Appendix number for image processing, with some improvements. After incorporating an image compression algorithm, the code was updated. The code was written in Raspberry Pi to print the results on the screen. By writing some codes in Linux, the result was redirected to transfer it via Bluetooth.

4. Results and Discussion

In the visual cortical stimulator role, software design is essential and includes three types of programming code:

- Code for image processing: code to control and automate the system. Linux commands were used to automatically link the parts of the transmitter and the receiver through Bluetooth. A push-button was also added, and for this purpose a command code was written.
- Code for communication purpose for data encodes and decodes: This is in the transmitter side for image processing using Matlab Simulink. It includes capturing images from the USB camera, resizing, converting images from RGB to the intensity form, applying the algorithm of the image simplification, and image compression.
- Code for a microcontroller to control the system: on the receiver side, C code was used for receiving data, image decompression, pulse modulation and sending data to the optrodes.

Figure 4 shows the flow chart of the software design. It starts with both the original scene and concludes with the data being sent to the stimulator.

Original scene: These are the live images captured by the USB Web camera. The speed of the stream of images is about 25 fps and can be adjusted by the time framing by Matlab codes and the number of iterations over the next step.

Scene simplification: In this stage, the scene is simplified with image cartoonization, tinted reduced outlined nature (TRON), and edge enhancement algorithms. Significant information is improved in a scene thus removing the high frequencies.

Entropy: It removes any discontinuity in the gradient image and increases the thickness of the edge by detecting the difference between the present and the previous frame.

Image compression: This reduces the size of the data transfer, resulting in communication bandwidth savings and reducing power consumption. This block essentially uses the most common technique for compression, which is the DCT. This DCT stage discards the meaningless information so that far less data is transmitted and can be achieved in two ways: blocking or zigzagging.

Data encoding: It rearranges data by re-sequencing data into a specific format before sending it wirelessly.

Data decoding: This is the reverse encoding method by translating the encoded formatted data into the original format.

Image decompression: The IDCT is used in this stage to restore the image. The main purpose of decompression is to convert the compressed data to the original number of coefficients.

Pulse encoding: It transforms each frame into several sub-frames according to the numbers of bits was used to describe the modulation of the pulse width to derive the uLED as shown in Figure 3.

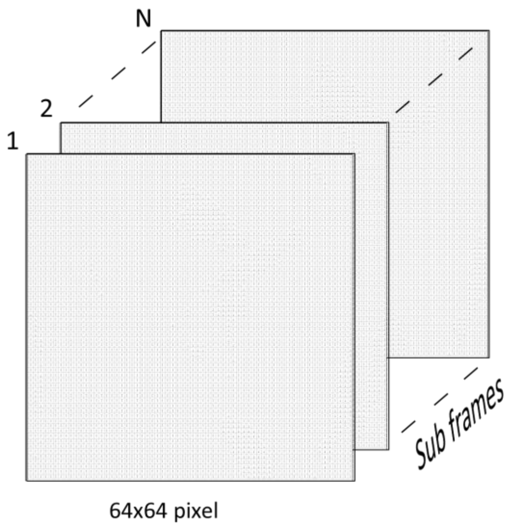

Figure 3: Received images were converted to multiple sub-frames. Each sub-frame was formed as different intensity levels to be displayed on µLED

µLED stimulator: Using 64x64 optrodes, this critical part of the implant excites (optically) the intended cortical neuronal region.

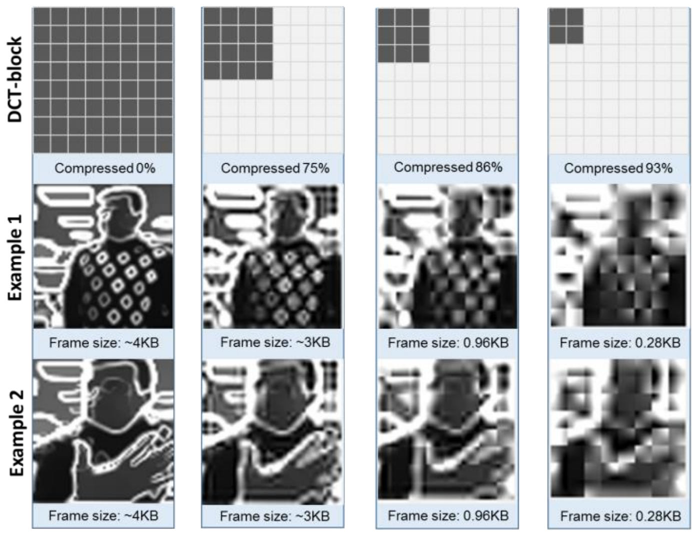

Figure 4: Shows different compression rates obtained at the receiver side (Implant device)

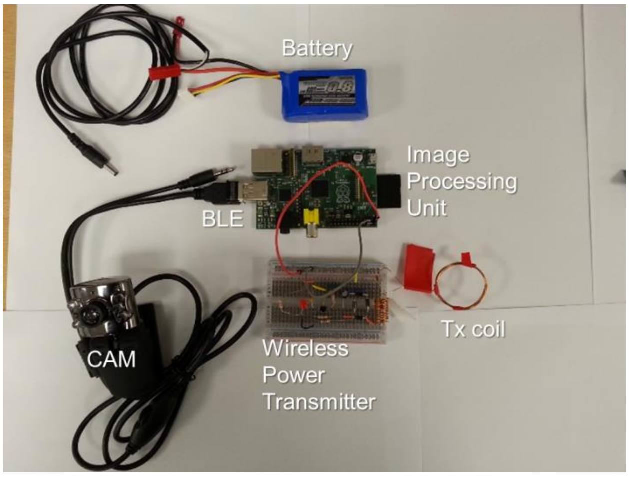

Figure 5: Transmitter hardware devices

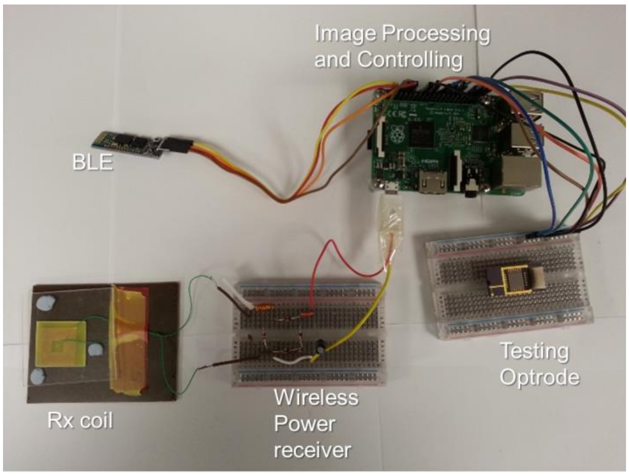

Figure 6: Receiver hardware devices

Other photo processing is compiled for both the transmitter and the receiver sides as well as for retinal imaging. To increase valuable information and reduce or decrease irrelevant information, image simplification is necessary. Using object cartoonization and edge highlighting, image smoothing is used for this purpose. Use the intended 64x64 frame size. The intended frame size of 64x64 is used. The maximum band width for 25 fps is approximately 800 kbps, which is much higher than the Bluetooth connection capability. The average baud rate at 170 kbps was reached. The compression of images is required to reduce the image size. A compression ratio of 86% was the preferred option at this point for image compression.

To convert images to the frequency domain, the desecrate cosine transform (DCT) was used. DCT is typically applied to 8x8 blocks. For the compression ratio of 86%, the 3x3 block was selected from each 8x8 block. This technique is named as DCT_block. Zigzag's diagonal scanning was another approach used during image compression to select the correct frequency domain elements. The comparison was made between both approaches, DCT block, and DCT Zigzag, and the outcome was very similar. On the transmitter side, Matlab Simulink has been used for image processing. Then the code was deployed to the Raspberry Pi Zero. The results of the processed data are printed to the regular output and then routed using the Linux commands to transmit over Bluetooth.

On the receiver end, the original data is retrieved using C code. Upon compilation, the received data for each frame is decompressed. The LPC4330 processes these data efficiently and quickly when the core frequency is high, but high power consumes when operating the microcontroller at a higher frequency. Using the Digital Signal Processing library (DSP) reducing power consumption as the microcontroller can operate at a lower frequency.

Each pixel in a 64x64 frame is in the character format ranges [0, 255] of intensity level. To run the µLED, if the entire range is used, the number of sub-frames will be 256. This process is known as pulse modulation. In this project, only 16 levels have been used for the intensity level. The µLED matrix is used as an illustration of stimulator optrodes. In the portion of the power consumption graph, the µLED power consumption is 3X higher than the LPC4330 board. The intended 3D optrode's power consumption should be less than the µLED matrix. It means that the implant devices ' total power consumption will decrease.

Conclusion

The main limitations and challenges associated with the medical implant devices that impose the selection of appropriate microcontroller were highlighted and discussed. The selected microcontroller was adequate to meet the mentioned challenges. In terms of results, the implanted visual cortical stimulator consumes around 80 mw and achieves image decompression and displaying algorithms in 19.55 ms when DSP is used, which allows live streaming. The overall system was fabricated on a rounded shape PCB with diameter of only 30 mm, thickness 2.68 mm and the weight are less than 3g. For the future design replacing MK64FN1MOVLL12 with the LPC4330 microcontroller because it is more efficient, less power consumption in the same range of frequency, smaller size, and more capability for serial communication.

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