Image Processor for Visual Prosthesis Based on ARM

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Abstract: Visual prosthesis is designed and developed to help the blind people to restore vision [1]. Image processor is an essential part of visual prosthesis. It receives image data from a camera, and fulfills specific image processing strategy to transfer image information to data forms that can be recognized by implanted stimulator. To extract useful information from original image and provide satisfying image processing ability are the basic requirements for the image processor. In this article, an image processor based on ARM Cortex-A9 processor running mobile operating system Android is introduced. Image processing algorithms such as edge detection are applied to provide vital information of the scene to the following components. Software optimizations like using native code and hardware acceleration are made to reduce the processing time. After optimization, this image processor can process a 640*480 image within 50ms. This work could become the foundation of future researches to build visual prosthesis with impressive processing ability and flexibility.

Keywords: Visual Prosthesis; Image Processing Strategy; Software Optimization

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Introduction

Visual disability can bring about a lot of inconvenience to people's life. Diseases such as retinitis pigmentosa (RP) and age related macular degeneration (AMD) can destroy the patients' retina cells and cause visual disability. As the effect of other treatment is not satisfying, visual prosthesis has been researched and developed as a potential way to restore vision for people suffering from these diseases [2]. Using microelectrodes to stimulate different places along the visual pathway (retina, optic nerve, or cortex), visual prosthesis can help people generate visual perception. Generally the visual prosthesis can be divided into two parts. The external part captures image information, processes it and transmits the result to the internal part. The internal part generates electrical pulse to stimulate the neural system according to information received from the external part.

For image processor of the external system, there are some special requirements. Firstly, the number of image pixels after processing should match the number of the electrodes implanted inside patients' body.

Although researchers have been working hard at it, the electrodes number is still limited to a small one (about 1000 electrodes at most [3]). The digital image from the camera usually contains millions of pixels, so downsample the images to a smaller scale is demanded. With this restriction, the image information provided to the stimulator is limited. So, the second requirement is to apply appropriate image processing strategy to extract the vital information of the image. Methods like extracting the region of interest in the image and using edge detection algorithm are used to help recognize object in complex scenes. Thirdly, the image processor is required to have good processing ability to carry out the processing in real-time. Usually this requires the image processing algorithms run faster than 20Hz, matching the normal flickering frequency for people with healthy vision ability. Lastly, the whole external system should have small scales and little power consumption to make it portable.

Many research groups have developed their own mobile image processing units. These models use the microprocessors based on different kinds of processors, which are mainly the DSP and ARM processor. At first, most of the researchers prefer DSPs (digital signal processors), which usually has the VLIW (Very Long Instruction Word) and multiple arithmetic units. These modules are helpful for data processing. To give an instance, Neha J. Parikh used several DSP platforms such as TMS320C6711 TMS320C5x platforms, as the image processor [5]. But the DSP is not suitable for some general purposed functions. Most DSP cores still need ARM cores as coprocessors. A few years ago, the ARM processor alone can't do the complex calculations efficiently. Wolfgang developed a vision support system based on an ARM 9 processor. The researcher has to make a compromise, by reducing the image scale before other operations, to achieve real-time performance. But in recent years, technology of the ARM microprocessor has leaped forward. By adding new module to its architecture, the ARM processor is also capable of doing massive calculations.

In this paper, an image processor based on ARM Cortex- A9 will be introduced. Other components which help to form the entire system for visual prosthesis are also represented. Image processing algorithms applied on this processor are demonstrated. It's proved that, with typical software optimization, image processing procedures, such as edge detection and downsampling, can be operated effectively on the ARM based processor. The whole processing strategy can be carried out in real-time. For future requirement of applying more sophisticated algorithms, other optimization methods are discussed.

Methodology

System architecture

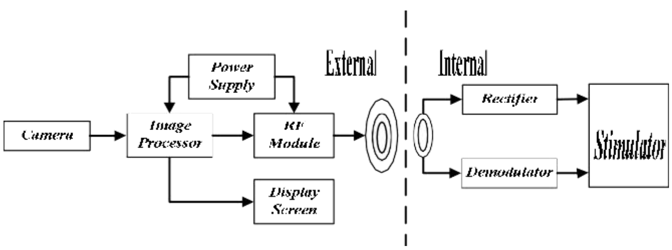

Fig.1. System architecture of visual prosthesis.

Fig.1. shows the system architecture of a typical visual prosthesis prototype. The internal part is made

up of stimulator and electrodes with the demodulator to decode data information and the Rectifier to supply energy. The external system contains the camera, image processing unit, RF (Radio Frequency) module, power supply and display screen. These two parts are joint together wirelessly by the inductive link.

The hardware of the external system used in this research is shown in Fig.2. In the picture, A represents the ARM developing board MarsBoard (Shenzhen Embest Technology, Shenzhen, China). The MarsBoard contains a 1.2 GHz Cortex- A9 ARM core i.MX6 produced by Freescale. The processor has 1MB L2 cache and the NEON coprocessors making it possible to complete calculation works in a short time. This developing board supports various interfaces such as two USB port, the GPIO port, the CMOS sensor interface (CSI) the LCD interface etc, making it a suitable unit to connect and control other components of the external electronic system. As for the peripheral components, an USB camera is used to capture images with a resolution of 640×480. A 3.5 inch LCD screen shows demons of the image processing result. It is also a resistive touch screen, so additional control can be added by using it. The portable power supply unit is a set of rechargeable Li-ion battery with 16AH power capacity. In the future design, these components can be assembled together into one portable device. RF module made up of EM4094 and the transmit coil are used to transform information from the developing board to the internal system. EM4094 is running at a frequency of 13.56MHz, with 200mW power consumption.

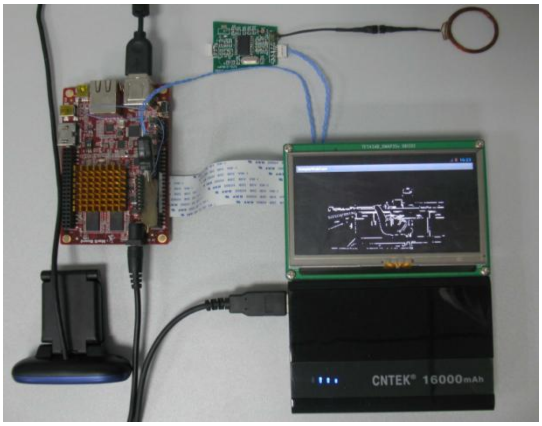

Fig.2. Demonstration of visual prosthesis external system

(A)ARM based developing board, (B) USB camera, (C) Portable power supply, (D) Display screen, (E) RF module (F) Transmit coil.

For the internal part, currently a micro stimulator VI1108 is designed to demodulate the data information and drive 16 electrodes to stimulate the tissue. Stimulator that can drive more electrodes is under development.

As for software development, Android is chosen to be the operating system for the image processor. The programming language applied is C/C++ and Java. The open source computer vision library (OpenCV, Version 2.4.9) is used to accomplish the image processing strategy. OpenCV contains many optimized image processing algorithms and can be used by multiplatform. So algorithms used on the desktop computer for feasibility verification can be easily transplant to the mobile devices with operating system such as embedded Linux, Android and iOS. Eclipse with the Android development tools (ADT) is used as the integrated developing environment.

These hardware and software form the visual prosthesis external system. To provide useful information to the internal system, a sequence of processing procedures are applied to the image processor. These processing procedures are combined to be the image processing strategy. In the following part, the design of image processing strategy is discussed.

A. Image Processing Strategy

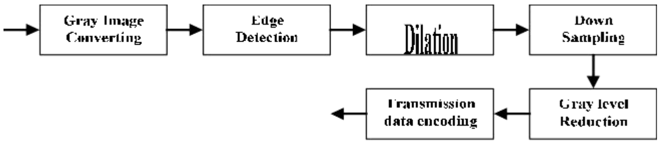

Fig.3. Image processing strategy for visual prosthesis.

The first bit informs the stimulator that the data transmission starts. The AMP and WIDTH bits control the electro pulse's amplitude and width value. EL1 represents the public channel of electrodes and EL2 represents the stimulus channel, the stimulus is generated between the stimulus channel and the public channel. At last, the parity check bit makes sure that the data transmitted correctly. The public channel is usually set to be the first channel, and the stimulus width is also fixed to a constant number to simplify the test. The image information comes ahead only affects the amplitude value. It varies in an image from one electrode to another.

The transmission data is exported to the RF module then transmitted wirelessly through the coupled coils to the internal part.

Currently the data form is targeted to the 16 electrodes stimulator. For stimulator with more electrodes, the EL bits need to expand to represent more electrodes. Same time with these registers. The VFP technology provides low cost for single-precision and double-precision floating point computation. These floating point computations can cost a lot of time with software implementation. To apply these hardware accelerations to the image processing procedures, particular compiler options are used. OpenCV for Android library are cross complied using CMake.

The options chosen for using hardware accelerations are "- mfpu= neon"-DUSE_ NEON= ON" "-DUSE_VFPV3=ON".

By using these options, the code can benefit from the hardware acceleration automatically.

Results

The processing result for each processing step is demonstrated in fig.4. The original image, with a resolution of 640×480, is first converted to gray scaled image, the edge detection, dilation algorithm are applied to the gray image. Then, the image is downsampled to a 32×32 array, and the gray level is reduced to five levels. Finally the image information is encoded and ready to be transmitted. These images are captured by the DDMS (Dalvik Debug Monitor Service) in Eclipse. It's the same that can be seen from the display screen. As can be seen, the edge detection algorithm extracts the object's margin which is vital for this image. The downsampling algorithm and gray level reduction algorithm kept this information in the final result. This image processing strategy is suitable for the single object recognition task. The integrated developing environment provides us convenient ways to test the processing speed of the algorithms. For program written with the Android, the Log file in the Eclipse is used to detect time consumption of each procedure. As can be seen in table III, after the optimization all processing gets faster. Most procedures' processing time get a 1.5-2.5 times promotion. The gray level reduction method gets a 47 times promotion. This is because of the different fulfillment of this method which is discussed in the program optimization section. The total processing time after optimization is 46.03 ms (21.72 fps), promotes 1.6 times comparing with the total processing time before optimization.

The canny edge detection algorithm cost most of the time. For application with faster speed, and lower image quality requirements, it is suggested to apply other edge detection algorithms with less processing costs, such as the soble algorithm.

Conclusion

In this paper, an image processor based on ARM Cortex- A9 is demonstrated. This processing unit has small scale and powerful image processing ability. The image processing strategy applied to this processor is demonstrated. After the software optimization, satisfying image processing speed can be achieved on this processor. It's proved that ARM processor alone can do the processing work required by visual prosthesis. Based on the external system introduced in this research, more complicated algorithms and sophisticated functions can be applied to achieve the goal of building more powerful and flexible visual prosthesis.

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