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A wearable real-time image processor for a vision prosthesis

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ABSTRACT

Rapid progress in recent years has made implantable retinal prostheses a promising therapeutic option in the near future for patients with macular degeneration or retinitis pigmentosa. Yet little work on devices that encode visual images into electrical stimuli have been reported to date. This paper presents a wearable image processor for use as the external module of a vision prosthesis. It is based on a dual-core microprocessor architecture and runs the Linux operating system. A set of image-processing algorithms executes on the digital signal processor of the device, which may be controlled remotely via a standard desktop computer. The results indicate that a highly flexible and configurable image processor can be built with the dual-core architecture. Depending on the image-processing requirements, general-purpose embedded microprocessors alone may be inadequate for implementing image-processing strategies required by retinal prostheses.

1. Introduction

Several research groups are developing retinal prostheses as a potential treatment for retinal degenerative diseases such as retinitis pigmentosa and age-related macular degeneration [1–4]. Many proposed designs require an image-processing device for acquiring images from a camera and transforming them into stimulus commands to configure the stimulation to be delivered by the implant. Details of the epi-retinal prosthesis being developed in the authors' laboratory have been reported previously [5]. In brief, a camera worn by a patient captures an image, sends it to a portable processor for decomposing into stimulus command sequences, which are then transmitted to an implanted device located within the eye via a transcutaneous radio frequency (RF) link. Electronics in the implant decode the signal and use the incipient energy of the transmitter to activate the microelectrodes (Fig. 1). It is clear from the above that the image processor plays an integral role in converting the visual scene into a representation for modulating electrical stimuli. Such a device is not unique to the described epi-retinal prosthesis. Vision prostheses proposed by several other groups also necessitate the use of an image processor. Notwithstanding its importance, little work has been reported on the hardware and software for such devices.

The design of such an image processor presents considerable challenges. The device should provide support for all essential activities that vision impaired subjects may need during their daily life, including: navigation [6], object recognition [7], facial recognition [8] and even reading [9–11]. However, vision prostheses of the near future are expected to contain only limited numbers of electrodes, thus constraining the visual resolution implant recipients are likely to perceive. Psychophysical studies of simulated pixelized vision on sighted patients suggest that non-trivial image processing may be

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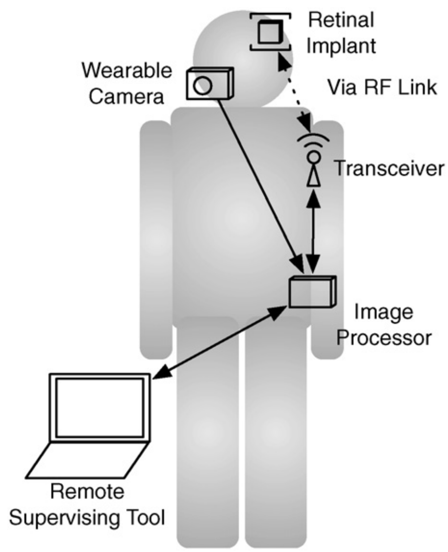

Fig. 1 – Components of a vision prosthesis. The image processor encodes images from the camera into stimulus commands and transmits them to the retinal implant via a wireless RF link. The remote supervising tool allows clinicians and researchers to configure the image processor using a separate computer.

required in order to maximally utilize the limited number of available electrodes [12–14]. Additionally, the image processor hardware needs to be portable yet able to perform possibly complex image-processing algorithms in real-time. The software on the device needs to be optimized for efficiency in power consumption and execution speed. Image acquisition and processing parameters should be easily configured to adapt to individual requirements of the patients. It has also been suggested that devices to be used in preliminary human trials should be equipped with a number of image-processing strategies in order to validate the efficacy of each [15]. Therefore it is prudent to have a scalable software architecture to support changes as the need arises.

Despite the aforementioned design considerations, only a few studies have hitherto addressed the issues. Buffoni et al. [15] reviewed psychophysical findings of pixelized vision, discussed the key constraints of image processing for vision prostheses and described a number of possible image-processing strategies. More recently, as part of their implementation of a sub-retinal vision prosthesis, Asher et al. [16] have presented a set of software algorithms for tracking, cropping, geometrically transforming, and filtering images from a camera into stimulation commands.

There are several advantages associated with stand-alone wearable image processors. Powerful hardware may be essential for executing the algorithms involved. This in turn leads to more complex circuitry, higher power consumption, bigger physical dimensions and higher heat dissipation, all of which are at odds with the requirements of an implantable device. By delegating image-processing tasks to an external processor the implant is freed from these additional complications. Furthermore, given that the implant will most certainly be a custom-designed application specific integrated circuit (ASIC), whereas the image processor can be built from commercially available components, many of which are already optimized for performance, power efficiency and size, savings in both hardware and software development time and effort will be significant. An external image processor is also more amendable to upgrades.

In this paper we present a wearable image processor based on a Texas Instruments OMAP processor running a customized version of Linux. A set of purpose-built software libraries and programs operate on the device to acquire images from the camera in real-time, perform image processing, and produce outputs, which can then be sent to a transmitter for subsequent delivery to the implant via an RF link. The software components have been carefully designed to provide real-time performance. The image processor is a stand-alone device capable of independent operation while being worn by a patient. It supports Bluetooth technology so that subjects can control various image-processing parameters using other Bluetooth-enabled devices. A complete suite of remote configuration tools have also been incorporated into the system, allowing researchers and clinicians to control the image processor as well as to experiment with various settings without physically accessing the device. Our work also indicates that depending on the image-processing algorithms involved, the hardware platform used needs to be selected carefully in order to attain real-time performance.

2. The image processor

2.1. *Hardware*

The hardware was manufactured by Spectrum Digital Incorporated (Stafford, TX, USA) and subsequently modified in our laboratory for further functionality. The device components relevant to the current discussion are summarized in Fig. 2. At the heart of the image processor is an OMAP5912 microprocessor (Texas Instruments, Dallas, TX, USA), which is primarily designed for embedded multimedia systems such as personal digital assistants (PDAs), or portable medical devices. The OMAP5912 has a dual-core architecture comprised of an ARM9TDMI general-purpose reduced instruction set microprocessor designed by ARM Limited (Cambridge, UK) and a

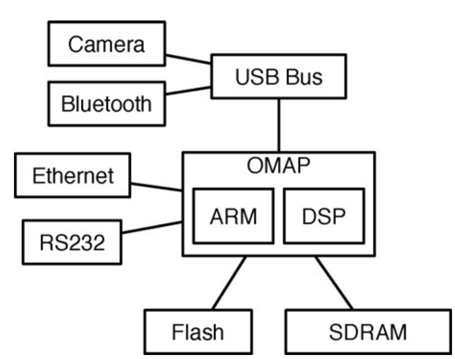

Fig. 2 – System hardware of the image processor. Peripherals are connected through USB. The image processor can communicate with other devices via Ethernet, RS232 and Bluetooth. Furthermore, flash memory and SDRAM are available for data storage.