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Microcontroller based fibre-optic visual presentation system for multisensory neuroimaging

Veldri Kurniawan*, Jane Klemen, Christopher D. Chambers

School of Psychology and Cardiff University Brain Research Imaging Centre (CUBRIC), Cardiff University, CF10 3AT, United Kingdom

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ABSTRACT

Presenting visual stimuli in physical 3D space during fMRI experiments carries significant technical challenges. Certain types of multisensory visuotactile experiments and visuomotor tasks require presentation of visual stimuli in peripersonal space, which cannot be accommodated by ordinary projection screens or binocular goggles. However, light points produced by a group of LEDs can be transmitted through fibre-optic cables and positioned anywhere inside the MRI scanner. Here we describe the design and implementation of a microcontroller-based programmable digital device for controlling fibre-optically transmitted LED lights from a PC. The main feature of this device is the ability to independently control the colour, brightness, and timing of each LED. Moreover, the device was designed in a modular and extensible way, which enables easy adaptation for various experimental paradigms. The device was tested and validated in three fMRI experiments involving basic visual perception, a simple colour discrimination task, and a blocked multisensory visuo-tactile task. The results revealed significant lateralized activation in occipital cortex of all participants, a reliable response in ventral occipital areas to colour stimuli elicited by the device, and strong activations in multisensory brain regions in the multisensory task. Overall, these findings confirm the suitability of this device for presenting complex fibre-optic visual and cross-modal stimuli inside the scanner.

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1. Introduction

Functional magnetic resonance imaging (fMRI) is one of the most widely used non-invasive research tools for investigating brain activity correlated with human behaviour. Most fMRI experiments utilize a projected LCD screen for presenting high-resolution visual stimuli. Although this standard visual presentation system is sufficient for most experiments, there are still many challenges in delivering visual stimuli for certain types of experiments such as visuomotor reaching tasks (Filimon et al., 2007; Culham et al., 2008) and multisensory visuotactile tasks (Macaluso et al., 2005). In some visuomotor reaching tasks there is a need to display visual stimuli at different depths in various locations near the subject's body or face, which is difficult to accomplish using an ordinary video projector (Huang and Sereno, 2008). Presenting visual stimuli in close proximity with the source of tactile stimuli is also important for multisensory visuotactile experiments, especially when investigating spatial aspects of intersensory interactions (Spence and McDonald, 2004; Macaluso et al., 2005). Besides this limitation, there are several reasons that serve to discourage the use of LCD video projectors for some applications of fMRI, including the impossibility of obtaining complete darkness (except with special filters, such as described in Kimmig et al., 2008), restricted field of view, and limited refresh rate (60 Hz for typical LCD projector).

An alternative method of displaying visual stimuli is using real objects inside the scanner, which sometimes need to be moved manually by a trained operator standing next to the scanner bore (Makin et al., 2007; Menz et al., 2009). Although practical and straightforward, the timing and the precision of positioning can become problematic in this case. As an alternative, several studies have also managed to use a group of light emitting diodes (LEDs) positioned at various locations inside the scanner (Marx et al., 2004; Culham et al., 2008). These LEDs were powered directly by electrical wires connected to a computer or an electronic control apparatus in the scanner control room. Using this approach, extra care must be taken to ensure that these wires are properly shielded (Gallivan et al., 2009), or they can cause unwanted heating or image artefacts produced by interaction of electricity flowing inside the cable with the scanner RF (radio-frequency) pulses and switching gradients. Moreover, this approach is feasible only for experiments that use small numbers of LEDs.

Several factors must be considered when constructing MRI compatible equipment, most importantly: the participant's safety; RF interference leading to image artefacts and heating hazard, interactions between the equipment and the static magnetic field, spatial restriction of the scanner bore, and leakage currents (Keeler et al.,

* Corresponding author. Tel.: +44 29 208 74007.
E-mail address: veldri@gmail.com (V. Kurniawan).

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1998). The problems associated with bringing conductive electrical wires that power LEDs into the scanner can be overcome by transmitting light emitted by these LEDs via fibre-optics instead (Huang and Sereno, 2008). Fibre-optics are completely safe in the MRI environment and do not lead to heating or RF interference. In some experiments, optical fibres have been used to relay high-resolution video images from CRT displays in a control room to a participant lying inside the scanner, operating as a binocular fibrescope (Cornelissen et al., 1997; Hoffman et al., 2003). However, instead of using fibrescopes to transmit entire visual images, for multisensory experiments, in particular, it can be more desirable to transmit point light sources emitted by the LEDs into various positions near a subject's body in 3D space. Additionally, LED light sources have wider contrast ranges compared to CRT or LCD screens and superior temporal resolution.

In most visual experiments, visual stimuli need to be dynamically updated in the spatio-temporal domain. Unlike ordinary video displays, this problem becomes challenging when LEDs are used to present stimuli. If only a few LEDs are required, usually they can be connected directly to a PC parallel port (which can control up to 8 LEDs) and then each LED can be turned ON/OFF by sending 0/1 to a corresponding pin of the parallel port. Another approach that efficiently accommodates more LEDs using a single parallel port has been demonstrated by Huang and Sereno (2008). The authors connected a parallel port to a custom made circuit that performs translation (demultiplexing) of 8-bit binary codes of the parallel port into a signal that activates one of 256 LEDs at once. There are, however, several limitations to this approach. First, the device can either activate one LED, or a prewired group of LEDs at the same time. More complex patterns can possibly be simulated by blinking several LEDs ON and OFF in rapid succession, however this increases the complexity of the required software. Second, slightly different wiring in the hardware circuitry is required for displaying stimuli in different experimental paradigms. Third, the control of brightness of each LED is very limited.

The challenge here, therefore, is to develop a general-purpose programmable digital device for controlling LEDs that can be utilized for various experimental paradigms. The device should be flexible enough to display various stimulus patterns simply by changing the software, without the need to modify the underlying hardware circuitry. In this paper we describe the design of a microcontroller-based fibre-optic LED stimulus presentation system that can be controlled from a PC via a USB port. The device was designed in a modular and extensible way so that it can drive up to several hundred LEDs, depending on the requirements of the experiment. Tri-colour RGB LEDs were used in this device to enable the display of various colours by specifying the brightness level of each red, green, and blue component (4096 gradation levels per colour). Additionally, colour, brightness, and timing of each LED can be controlled independently, which enables greater flexibility for displaying various visual stimulus patterns, analogous to manipulating pixels on an LCD screen. Any popular programming language with an access to USB port (such as Matlab® or C++) can be used to command the device, and we provide example Matlab® code (see Supplementary Information).

2. Materials and methods

2.1. Design concepts

The fibre-optic system consists of several components, including a microcontroller-based digital hardware, software for programming the microcontroller, software for interfacing between the microcontroller and a PC, and some supporting structures for holding the optical fibres. In this paper, we describe the design and implementation of the hardware and software for controlling 80 LED fibre-optic point lights.

One aim of constructing this fibre-optic visual presentation device was to complement the tactile stimulator system that we currently use for multisensory visuo-tactile fMRI experiments. The tactile stimulator was manufactured by Quaerosys™ and consists of several stimulator modules driven by MRI-safe piezoelectric components. Each module contains 20 small plastic pins (1 mm in diameter) arranged into a 4×5 grid as shown in Fig. 1a. The position

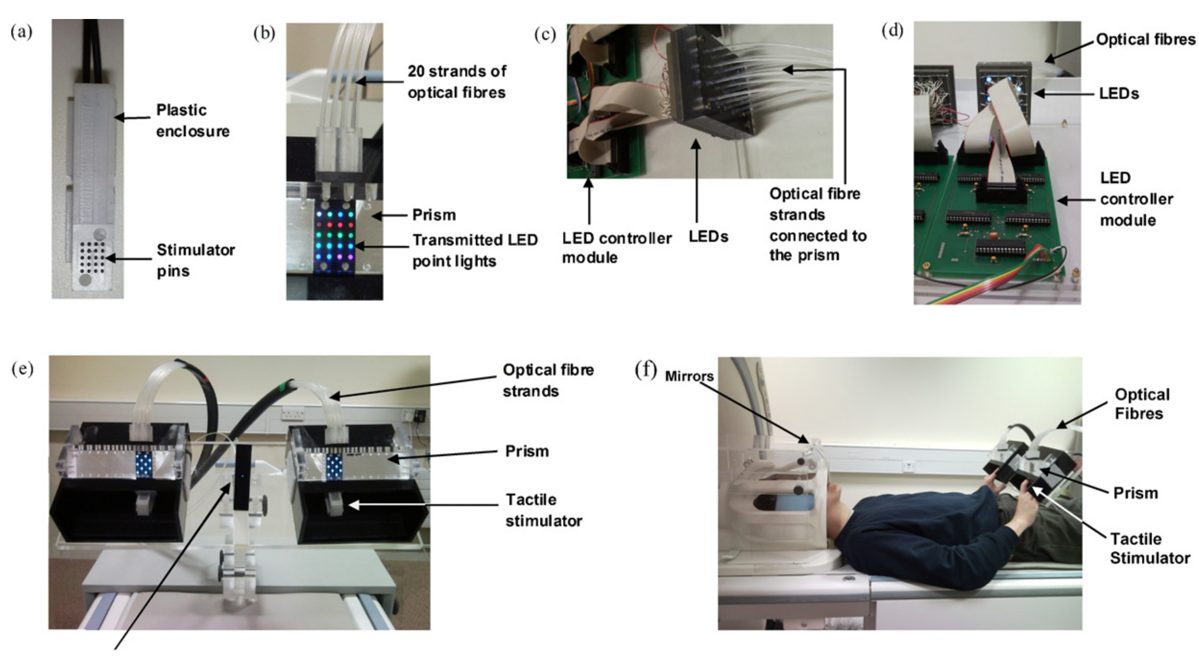

Fig. 1. (a) An fMRI compatible tactile stimulator module (Quaerosys™) with a 4×5 grid of plastic pins. (b) A single fibre-optic prism displaying 20 LED light points, arranged into a 4×5 grid. (c) In the MR control room, 20 strands of optical fibres were connected to 20 LEDs. (d) Close-up view of the LED controller module. (e) Supporting structures made from Perspex material for mounting both tactile stimulators and fibre-optic prisms in place. (f) Example of multisensory experimental setup with a subject, two fibre-optic prisms and two tactile stimulators.

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