An electronic device for nerve stimulation

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1. Introduction

Mivip is a three-years research project funded by the European Union; it aims at realising microsystems based prototypes in the field of rehabilitation engineering, and at demonstrating the efficiency of a functional prototype of visual prosthesis interfaced with the optic nerve. Blind persons whose optic nerve might be still functional, among which some people with Retinitis Pigmentosa, should benefit from this visual prosthesis.

The final Mivip prototype (Figure 1) planned at the end of the project will include

- an artificial eye,
- an external processor,
- a transcutaneous power and data RF link,
- a neurostimulator
- an implanted package with connection feedthroughs,
- a spiral cuff electrode wrapped around the optic nerve.

In a first phase of the project, an external stimulator will be connected to wires going through the skin of a patient to an implanted spiral cuff electrode. The external stimulator is designed to be used in other nerve stimulation experiments; the purpose of this paper is to describe the external stimulator. More specific information about the Mivip project can be found at the URL http://www.dice.ucl.ac.be/mivip.

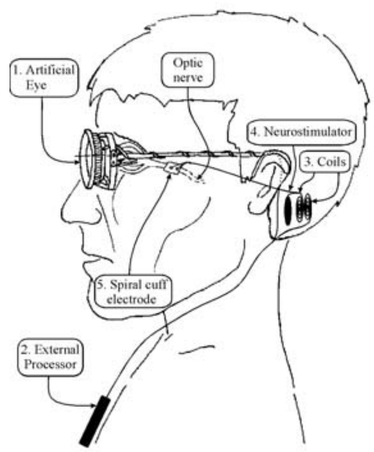

Figure 1 : Mivip prototype

2. The neurostimulator

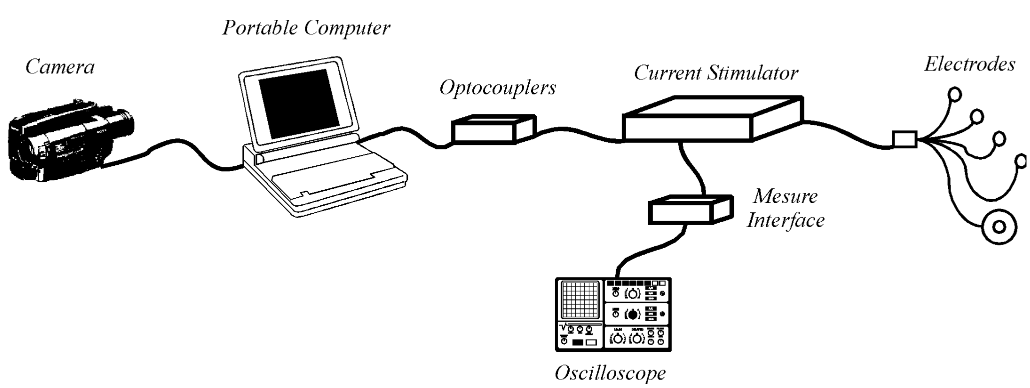

Figure 1: stimulation environment

Figure 1 show the complete stimulation environment designed in the frame of the Mivip project. The camera is not used at the moment. Instead, standard current waveforms are programmed in the portable computer, and sent sequentially through the current stimulator to the electrodes.

Opto-couplers isolate the current stimulator and the electrodes from the external world, for safety reasons. The current stimulator contains four programmable current sources. A measurement interface is provided in order to connect an oscilloscope to visualise current or voltages on the electrodes; this interface is also isolated by opto-couplers.

The whole system, including the computer, operates on batteries. Separate batteries are used at both sides of the opto-couplers. Other protection circuits, including a serial capacitor, are provided at the output of the current stimulator.

3. Hardware

3.1. Stimulators

The global block diagram of the current stimulator is given in Figure 2.

The stimulator mainly relies on four current sources which are controlled by a programmable digital component, a FPGA. This FPGA acts as an interface between the PC and the sources, providing digital data to each of them, and ensuring their synchronism. The system also includes a power supply circuit, a measurement circuit and optologic interface with the external world.

The current sources specifications are listed in Table 1.

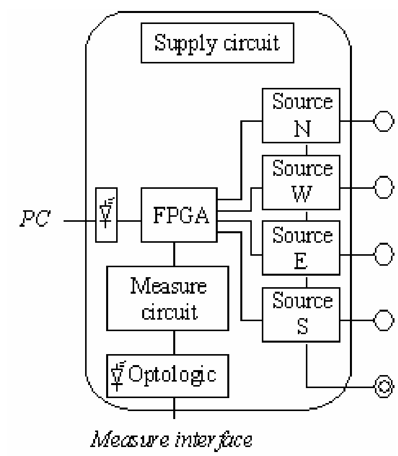

Figure 2: Global block diagram of the current stimulator

Resolution	11 bits
Dynamics	-10 mA to 10 mA
Elementary current step *(S_c)*	10 µA
Maximum establishment time *(t_e)*	1 µS
Elementary time step *(t_s)*	10 µS

Table 1: Current sources specifications

These characteristics are illustrated in Figure 3.

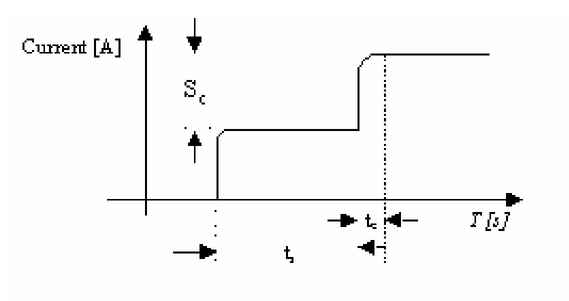

Figure 3: Specifications on current steps

3.2. Measurement interface

This interface converts analog values to digital words with a precision of 11 bits. Possible measurements, in direct interaction with the sources, are :

- current in the sources (4 possibilities);
- voltages at the electrodes (4 possibilities);
- voltages between two electrodes (6 possibilities).

The circuit is used during operation, but also for the fine calibration of the current sources. Currents are measured through voltages differences between the terminals of series resistors. The measured voltages go through instrumentation amplifiers, which isolate and amplify the signals; gains are adjusted to correspond to the input dynamics of a 12 bits A/D converter, controlled by the FPGA. Only the 11 MSB are used, and transmitted to the outside world through optocouplers for a perfect isolation. Visualising these signals on a scope then necessitates an external D/A conversion.

3.3. Safety aspects

The whole system is designed to operate in full safety with the patient. In particular:

1. 6V batteries provide the power supply for the whole system. Separated batteries are used at both sides of the opto-couplers.
2. Grounds at both sides of the opto-couplers are separated for safety reasons. All connections between the PC and the current stimulator also go through opto-couplers.
3. All measures (see section 3.2) are converted into digital words, in order to be transmitted to the external world through another set of opto-couplers.
4. Currents from the current stimulator goes through a set of four series capacitors (one on each current source). The role of the capacitors is to act as a natural limitation for the total charge injected on an electrode, as well as to control the balance of the injected charges (positive and negative charges must be equal for physiological reasons).
5. Charges cannot be balanced exactly by programming the current stimulator, because of the finite precision of the sources. A supplementary analog charge recovery circuit is thus added in order to complete the balance of charges at the end of each stimulation.
6. Each current source contains an electrolyse detection circuit in order to warn the user of the possibility of damage on the electrode contacts.

4. Software

A user friendly interface has been realised in order to allow the users to define the stimulus and to send them to the stimulator. It is based on three main windows: the Control Panel, the Waveforms Editor and the Waveforms Setup (Figure 4).

The Control Panel manages all the sets of waveforms recorded in a database: creation, deletion and edition of sets is performed inside this window. It calls the Waveforms Editor window to edit a particular set. This window displays the four waveforms corresponding to each electrode. A waveform is divided in a certain number of pulses, each pulse being repeated at a certain frequency for a given time. These parameters are defined by the user.

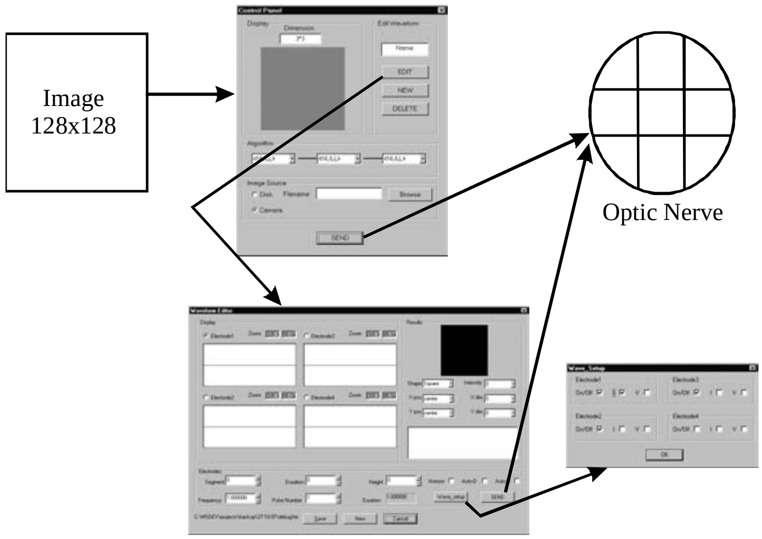

Figure 4: software interface

A pulse is divided into a certain number of linear segments defined by three parameters: its number in the sequence, its length (in µs) and its amplitude (in µA, coded on 11 bits). By changing one of this parameters, the user displays in real time the new pulse in the window. The Waveforms Setup is called by the Waveforms Editor in order to specify configuration parameters. First, the users can specify which electrodes will be used. Then he can specify which measure will be applied during the stimulation: current, voltage or voltage difference.

In order to be able to automate all the stimulation, a script language was defined. It mainly allows to change all the waveforms parameters (length, height, frequency number of pulses), and to select and to send a set of waveforms. It is also able to interlace a certain number of sets, to choose randomly a set to be applied...

This interface works in real time with the stimulator. Every 20µs, 64 bits have to be sent; this requires a transfer rate of 3.2 Mbit/sec. In order to allow real time, the sequence of bits are stored in a 32Mbyte buffer (inside the PC Ram) before being sent through an extended parallel port (EPP) at its own rate (800 kbyte/sec). This buffer allows to store a sequence of up to 80 sec.

5. Conclusion

A current stimulator has been designed for a research project on visual rehabilitation. Its characteristics make it suitable for further use in other nerve stimulation experiments. Safety circuitry and a user-friendly interface were particularly emphasised. An implantable VLSI integrated version of the stimulator is currently under design.

Acknowledgements

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