Developing and Managing a Stimulation Environment for a Functional MRI Using NI LabVIEW, PXI, SCXI, and NI CompactDAQ Systems

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- Bruno NAZARIAN, Centre IRMf

The Challenge:
Developing a strong, upgradable, and modular stimulation bench for cerebral functional magnetic resonance imaging (fMRI) experimentation to correlate, validate, and simultaneously record cerebral activation in humans with diverse behavioral data such as physiology, cognitive, and motor responses in addition to visual and olfactory stimulation.

The Solution:
Using NI LabVIEW software to coordinate the architecture of an experimental bench based on PXI, NI CompactDAQ, SCXI, and vision devices for eye-tracking applications.

Author(s):
Bruno NAZARIAN - Centre IRMf

Cerebral fMRI is one of the fundamental pillars of clinical research in the neuroscience field, which consists of studying the correlations between cerebral “activations” (measured by MRI) and the “behavior” of the subjects. Cerebral activation is synonymous with local variations in cerebral hemodynamics. The subject is exposed to a set of stimuli (visual, auditory, tactile, and olfactory) and their behavioral responses (cognitive, motor, and physiological) are recorded.

At our fMRI technical support center in Marseille, France, we work to implement the technical and human needs that relate to experiments conducted by scientists and doctors, as well as perform a great deal of research and development on stimulation environments synchronized with MRI acquisitions, which is a field that requires continual development. We target our efforts toward the development of hardware and peripheral factors such as subject responses, sensors, and stimulators, as well as the controlling software.

Using Expensive and Inflexible Solutions

Creating stimulation and behavioral data collection systems requires extensive research and development. Specialized companies with diverse strategies work to market many peripherals such as complete ranges including an I/O unit, peripherals alone, and customized developments, which are usually expensive. In addition, most developments typically relate to the hardware portion, sometimes in combination with a closed, limited software program.

We developed a system that integrates software and hardware elements while guaranteeing easy maintenance and the ability to upgrade a part or the whole system to add new functionality. By integrating naturally complementary and upgradable hardware and software components from NI, we met our criteria for nearly the entire system.

Our configuration consists of an NI PXI-1031 chassis with an NI PXI-8108 embedded controller running LabVIEW and additional modules including the IMAQ Vision Library and the NI Sound and Vibration Measurement Suite; an NI PXI-6528 industrial digital I/O module that synchronizes the MRI machine and the modules on the stimulation bench; an NI PXI-6289 M Series multifunction data acquisition.

(DAQ) module that records analog data; and an NI PXI-1409 image acquisition module for video data treatment and eye tracking. The core system also includes two signal conditioning systems: an NI SCXI-1000 chassis and an NI CompactDAQ chassis used to acquire physiological data in the MRI room.

Three Layers of Architecture

The stimulation environment has three distinct layers. The peripheral layer is a set of devices in contact with the subject and allows interaction with stimuli such as keyboards, trackballs, joysticks, force sensors, temperature sensors, and physiological sensors, which monitor heartbeat, respirations, and galvanic skin response. We also included visual, auditory, olfactory, and tactile, or more specifically eye tracking, as forms of stimulation.

The hardware layer is made up of all the instruments that interface with the peripherals such as sensor excitation and analog input including conditioning reading, digital input reading, and video. This layer is important for precise synchronization of all acquisition/stimulation devices with the MR scanner. We achieved all of these tasks using PXI, SCXI, and NI CompactDAQ devices.

The software layer is the real asset of the bench because it coordinates and controls the hardware layer and must be ergonomic and reliable so the user can program various experiments in a quick and reliable way. The modularity and integration of LabVIEW software, in particular via NI-DAQmx and NI-IMAQ drivers, with the hardware layer fully meet this specification.

Synchronizing the Behavioral Acquisitions with the MR Scanner

Because the fMRI technique seeks correlations between cerebral activations and subject behavior, we have to perfectly synchronize both the MRI and behavioral acquisitions by using the timer from the MRI machine, which is a trigger for starting cross section (MRI acquisitions, overtime, and 3D volumes divided into cross sections). This trigger consists of a digital transistor-transistor logic (TTL) signal, which has a temporal precision of less than a microsecond.

We used a particularly flexible technique, illustrating the integration of software and hardware that is specific to LabVIEW and NI modules. We programmed a time source, which uses LabVIEW to “control” a timed loop and manage the synchronization between the various acquisition/stimulation modules, based on the detection of front changes on a digital line on the PXI-6528 module.

“Simple” Analog Input and Signal Conditioning

One of the core modules for our test bench is the analog input and signal conditioning module for accurate acquisition of relatively slow analog signals at a sampling frequency less than 1 KHz. In this frequency range, we use equipment such as force sensors, thermistors, respiration sensors, and potentiometer measurements.

Our solution consists of a PXI-6289 module mounted on an NI SCXI-1000 chassis into which we integrated a set of specific conditioning modules including the SCXI-1120 eight-channel isolation amplifier and the SCXI-1121 four-channel isolation amplifier with excitation at constant voltage or current.

Electrophysiological Signals: A Serious Problem in fMRI Experimentation

Recording electrophysiological signals such as electromyograms and electrocardiograms is a serious problem in the fMRI field. Because the signals are highly polluted by the MR scanner we have to reduce the length of the cables connecting the subject to a preamplifier and the digital-to-analog convertor (DAC), commonly located in the acquisition modules, to limit noise.

Another element that complicates our solution is that we have to filter any electrical signal that crosses the Faraday cage of an MRI room to avoid radio-frequency pollution. These filters can cause leak currents, which does not affect low-frequency signals such as force sensors but has a negative impact on electrophysiological signals. We place a nonmagnetic NI CompactDAQ chassis in the MRI room onto which the necessary preamplifiers are wired. The USB connection cleanly crosses the Faraday cage via two USB/optical and optical/USB converters and connects with the PXI-8108 controller.

Video and Oculomotricity

We also developed a modular solution for recording oculomotor data. We structured this system around a real-time acquisition and treatment system including a nonmagnetic analog NTSC-format charge coupled device (CCD) camera, a PXI-1409 image acquisition module, LabVIEW, and the IMAQ Vision Library.

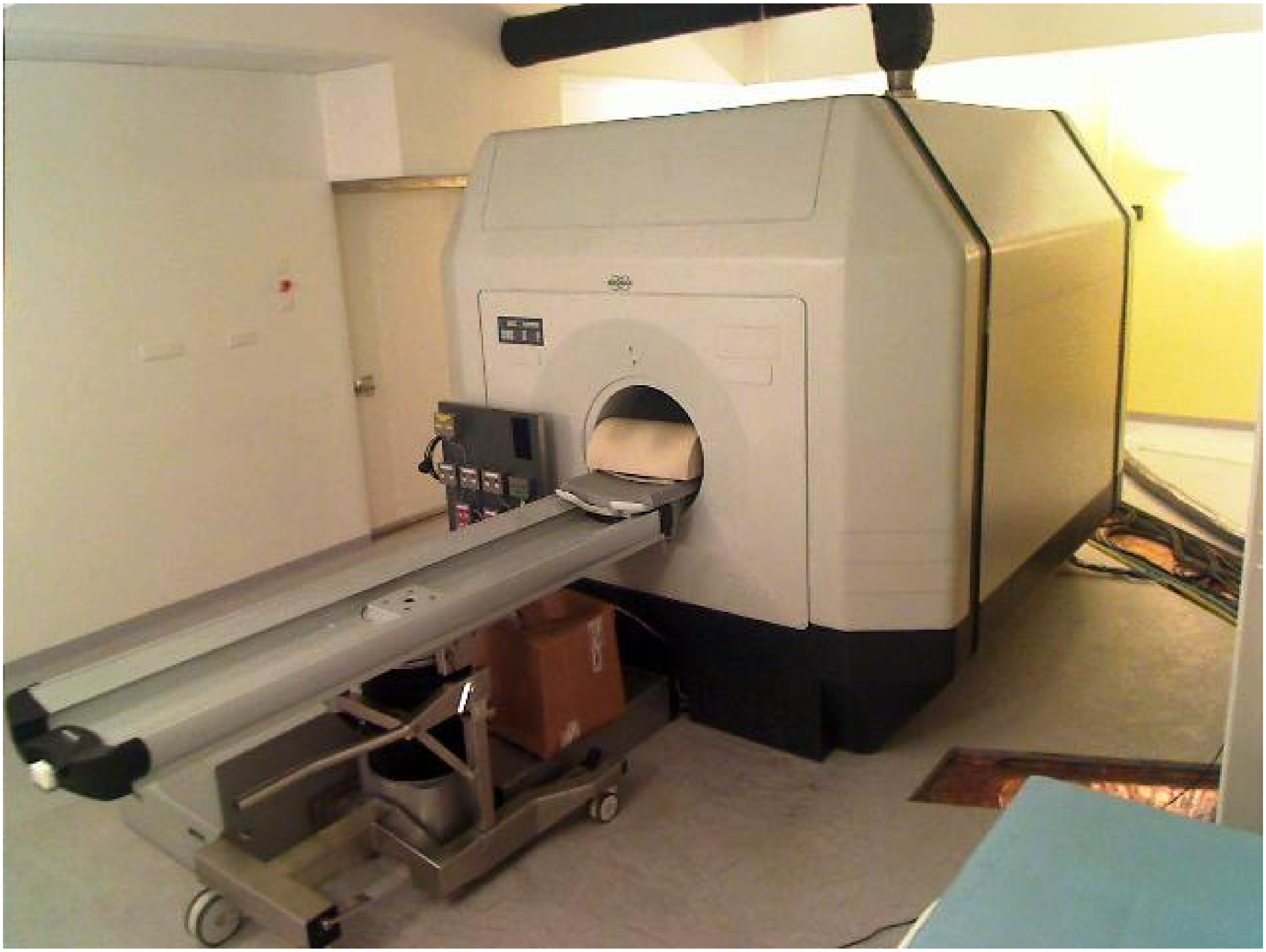
With this solution, we can acquire the position of the center of the pupil and its relative dilatation at 60 Hz. Our system is not sensitive to intersubject variability due to eye color or the presence of corrective lenses, which is the subject of another case study.

Easy to Duplicate, Maintain, and Upgrade

Our new stimulation environment is completely modular and can be easily duplicated, maintained, and upgraded with the evolution of regular NI products. It is also easy to improve by independently developing new forms of stimulation, or recording and integrating them into the existing bench.

The modularity of this solution would not have been possible without the integration of NI hardware and software components that are naturally complementary and upgradable. The NI-DAQmx and NI-IMAQ drivers, which have great flexibility and adequate conditioning for the SCXI and NI CompactDAQ systems, guarantee optimal use of the I/O devices and allow LabVIEW to efficiently orchestrate our stimulation bench, which we are constantly improving.

Author Information:
Bruno NAZARIAN
Centre IRMf
CHU Timone - Sous-sol IGH - 264, rue Saint-Pierre
Marseille 13005
France
Tel: +33 (0)4 91 38 69 44
Fax: +33 (0)4 91 38 47 57
Bruno.Nazarian@univmed.fr



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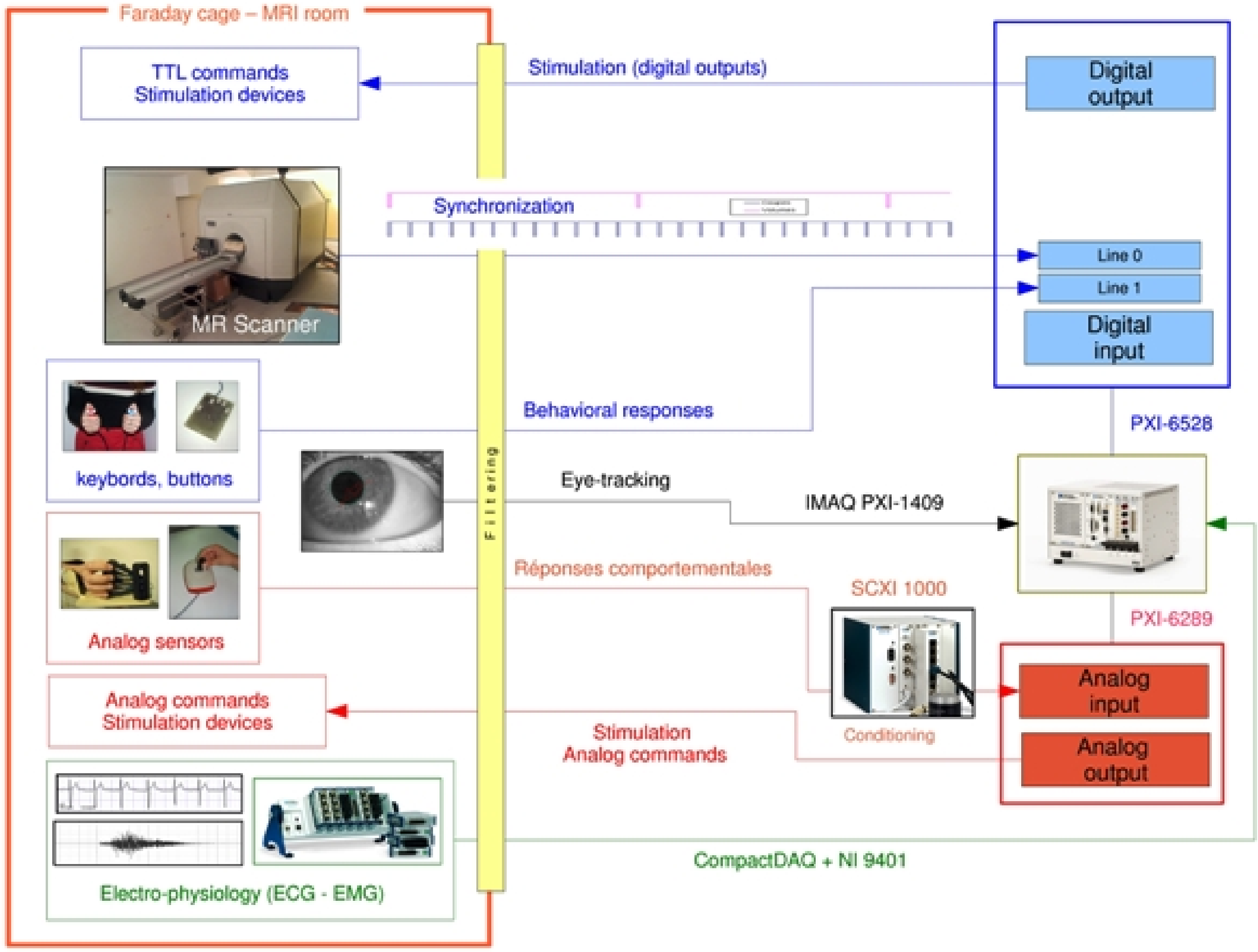

Functional Representation of the Stimulation Bench
