MEDUSA: A Scalable MR Console for Parallel Imaging

P. Stang[1], S. Conolly[2], J. Pauly[1], and G. Scott[1]

[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Bioengineering, UC Berkeley, Berkeley, CA, United States

INTRODUCTION:

Parallel excitation and reception hold great promise for MRI yet make tough demands on console hardware. High data rates, synchronization, scalability, and cost present important challenges. Implementing large multi-channel MR systems with efficiency and flexibility requires a scalable modular architecture. With Medusa, we propose an open system architecture using the Universal Serial Bus (USB) for scalability [1], combined with distributed processing and buffering to address the high data rates and strict synchronization required by multi-channel MRI. Medusa uses a modular design concept based on digital synthesizer, receiver, and gradient blocks, in conjunction with fast programmable logic for sampling and synchronization. We wish to determine the scalability limits of our distributed modular MR system while exploring applications in parallel MRI systems.

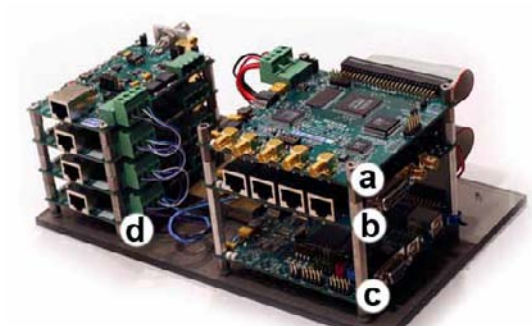

Figure 1: A stand-alone 1-channel Medusa console assembled from (a) one RF and (b) one Gradient module connected to (c) a Controller with USB2.0 interface. In the background is a stack of gradient DAC boards (d).

METHODS:

A Medusa MR console (Figure 1) is built from an extensible set of intelligent RF and Gradient modules which provide the core functionality required by MRI. Each module has local synchronization logic, a Direct Memory Access (DMA) engine, and a 2-megabyte waveform buffer. The logic and DMA functions are implemented in an Altera MAX-II EPM1270 Complex Programmable Logic Device (CPLD) that allows modules to perform sampling and synchronization on their own with no CPU overhead. Each RF module provides one exciter and receiver channel based on the Analog Devices AD9854 and AD6620 digital RF components. Each Gradient module drives four LTC1592 16-bit D/A converters via an optoisolated 10Mb/sec serial link, and provides 12 lines of gating control. Up to 16 modules are connected via a backbone bus to the Medusa Controller. In the Controller, operations are coordinated by a Philips LPC2214 32-bit ARM microcontroller, and module data streams are multiplexed into a CY7C68013A USB 2.0 interface IC for transfer to the upstream host PC. The controller also provides common clock and phase reference signals to keep modules synchronized. Multiple Medusa controllers, each with a module stack, can be connected to one or more host PCs. For system scalability and portability, the host PC control software is layered. A low-level Console Server makes the console hardware available via a unified IP network or Dynamic Link Library (DLL) interface. We have developed gradient-echo and spin-echo 2DFT imaging sequences in Matlab and use the Matlab-Executable (MEX) interface to drive the console directly and perform on-the-fly image reconstruction.

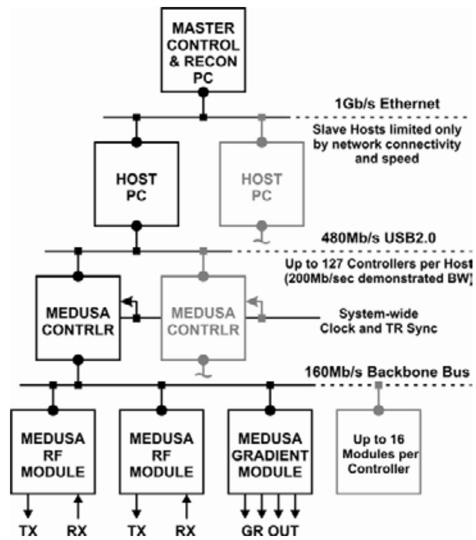

Figure 2: The Medusa architecture illustrating modular design and scalability. For small systems, the Master and Host PC functions may be collapsed into one machine. As the channel count and data rates grow, work may be spread over multiple computers.

RESULTS:

We have demonstrated GRE and SE imaging (Figure 3) with a single-channel Medusa console driving Stanford's Pre-Polarized MRI hardware [2]. A 2-channel Medusa console has been demonstrated on the bench. We have tested the RF modules at sample rates up to 1 million complex samples/sec (500KHz RF BW), and they can transmit and receive on carriers from DC to 66MHz (1.5T) without external RF mixers. The Gradient modules achieve output sample rates of 350K 16-bit samples/sec on each of four DAC channels. The Medusa backbone bus supports 20 megabytes/sec data transfer, while each controller's USB 2.0 interface can deliver 25 megabytes/sec to the upstream host PC. Power consumption for a single-channel Medusa console is 6.2 watts plus 5.3 watts for four gradient DAC boards. Total hardware cost for the single-channel Medusa system is approximately $900.

DISCUSSION:

The local DMA engine and waveform buffer on each module are key to achieving high data throughput. The DMA system maintains time-critical sampling operations independent of the Controller CPU, leaving it free to manage data flow. Deep 2MB buffering permits data readout and refill even while the next TR is in progress. Figure 2 shows the structure and data rates at each level of the architecture. Assuming continuous RF acquisition at 500KHz BW, one Medusa Controller has the capacity to service up to 4 RF Modules and one Gradient Module. Additional RF channels are easily accomodated by connecting more controllers.

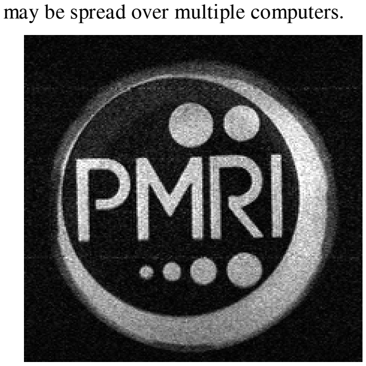

Figure 3: Image of acrylic-cutout phantom in water, acquired using the Medusa Console (Figure 1) on the Stanford PMRI scanner.

CONCLUSIONS:

We have demonstrated a single-channel version of our Medusa console with RF and gradient performance comparable to typical commercial systems. By adding modules, Medusa can scale easily, extending this performance to arrays of transmit and receive RF channels, as well as multiple gradient banks. Applications include Rx and Tx-SENSE, B1 shimming, and coil-array decoupling. We are currently manufacturing additional RF modules and developing experiments to fully evaluate Medusa's multi-channel capabilities.

REFERENCES:

[1] A Scalable Prototype MR Console Using USB, P. Stang et al., Proc 14th ISMRM, p1352, 2006.
[2] A Prepolarized MRI Scanner, G Scott et al., Proc 9th ISMRM p610, Glasgow 2001.