WHITE PAPER

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TEXAS INSTRUMENTS

Multicore processors bring innovation to medical imaging

Introduction

At a time when the cost of health care has received unprecedented scrutiny, advances in processor technology for medical imaging equipment have become a bright spot on a darkening horizon of escalating costs. Specifically, the need for more portable, lower power and cost-efficient medical imaging systems that don't compromise imaging quality plays into the strengths of systems with multiple processing engines, each dedicated to tasks that best suit its abilities.

Imaging systems based on either a hard-wired, non-programmable processor or on a specialized graphics processor cannot match the flexibility, scalability and power efficiency required by the next generation of portable medical imaging equipment. In contrast, multicore digital signal processors (DSPs) – whether a heterogeneous system-on-chip (SoC) with a DSP core and general-purpose processor (GPP) or a homogenous SoC with multiple, similar DSP cores – bring the best of both worlds to bear on the challenges of medical imaging. Emerging medical imaging systems are in turn begetting exciting new diagnostic procedures and treatments that continue to improve the quality of medical care.

Meeting health care challenges

Medical care is changing rapidly, and imaging systems based on multicore DSPs effectively complement today's trends.

Traditionally, due to cost and sheer size, access to sophisticated medical diagnostic systems has been found mostly in densely populated urban areas, where expert diagnosticians and technicians are available to operate them. Recent advances in embedded processor technology have made it possible for high quality and highly capable medical imaging systems to become much more portable and cost efficient. With sophisticated medical imaging equipment available in smaller clinics in outlying and rural areas, local technicians could telecommunicate diagnostic images to urban centers, where experts provide recommendations and real-time support. As a result, medical diagnosis can now be brought to the patient, rather than transporting a patient with a life-threatening condition to a medical imaging facility.

Other issues currently being discussed in the medical field are also well served by advances in processor capabilities. In some cases, these issues are at odds with one another. For example, many medical experts are calling for improved image quality, while at the same time seeking to reduce exposure to the harmful radiation that results from X-rays and nuclear imaging techniques. In the past, image quality could only be improved if radiation was increased, or through an invasive procedure.

Imaging systems with multicore DSPs offer another alternative, where innovative and efficient image-enhancement techniques such as edge detection, contrast enhancement, noise filtering, etc. can be easily programmed into one or more DSP cores to improve image quality without increasing the level of radiation or even make up for a decrease in radiation exposure to the patient.

The powerful real-time processing capabilities of multicore DSPs are accelerating innovation in diagnosis and treatment. Research experiments can be completed faster, and newer real-time image processing techniques can be developed and optimized with the easy programmability of multicore DSPs. Some examples of this can be seen today, as researchers are looking at how ultrasound waves might be applied to non-invasively detect thyroid cancer, cauterize wounds, or destroy small tumors. In the field of optical coherence tomography (OCT), researchers are investigating the use of light waves for a variety of diagnostic procedures, ranging from the detection of ear infections to more complex diagnoses like the early detection of diabetes by scanning the eye. These new applications of traditional imaging techniques can make their way quickly to real products with multicore DSPs.

Today's multicore DSPs also bring a high level of system integration with reduced power consumption and a small form factor. This can mean fewer processors on a board, smaller power supplies, reduced cooling requirements and less overall system cost. This translates to more people having access to medical care across the globe and more sophisticated tools becoming available in operating rooms, emergency facilities, ambulances and perhaps, someday, even in the home.

Strength in numbers

The typical medical imaging processing chain can be broken into three main stages: image acquisition, image conditioning and image display. See the example in Fig. 1

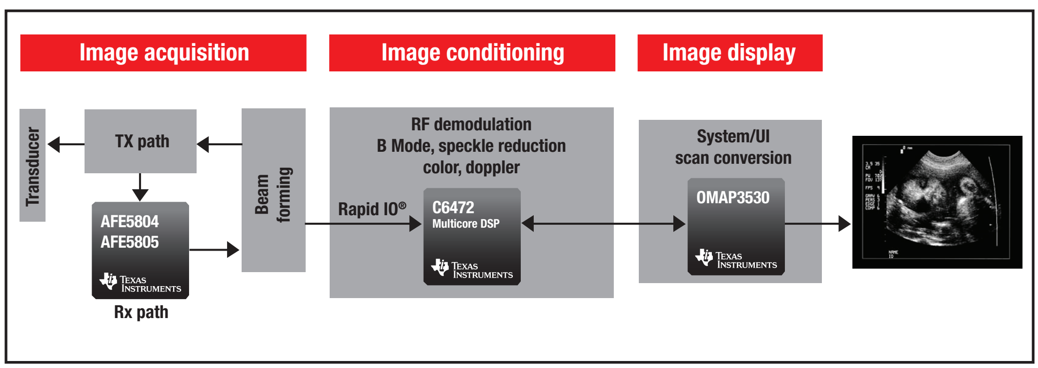


Figure 1: Typical ultrasound signal processing path

Homogenous multicore DSPs can provide the processing horsepower needed for the compute-intensive applications typical for the image conditioning and reconstruction that occur after image acquisition and before image display. The heterogeneous multicore SoCs can split the system management/user interaction and image-display preparation functions between a GPP core and a DSP core .

Image acquisition. Any one of five different kinds of analog wave types have been deployed in medical imaging systems: sound, light, radio, X-ray and nuclear. The imaging system receives the analog waves and converts them into digital signals, then typically uses a predefined set of front-end processing parameters and algorithms to interpret the raw digital data based on a pre-established region of interest in the body. For example, an ultrasound machine for cardiology has a set of front-end parameters relative to the heart and chest cavity, while an OB/GYN ultrasound machine is programmed with parameters and algorithms that acquire raw data in terms of a fetus in the womb.

Typically, the challenge in acquisition is managing and processing large amounts of image data in real time. To address these needs, the current generation of multicore DSPs has several high-bandwidth I/O options that – in conjunction with an intelligent DMA engine – can seamlessly bring in image data from an analog front end into either on-chip or off-chip memory for processing. A shared memory architecture allows the many cores to either operate on various sections of the image in parallel or to perform different processing functions on the same section of image data in serial. This gives the design team flexibility on how to architect the system, as well as making it easy to use the same acquisition system for multiple imaging applications.

Image conditioning. Once image data is acquired, it must be reconstructed into one or more visual images. In addition, imaging systems can also enhance the image to improve its definition. In previous generations of medical imaging systems, the quality of the image acquisition process was the limiting factor in the quality of reconstructed images. Now, however, sophisticated signal conditioning algorithms can filter out extraneous noise and other anomalies, thereby enhancing tissue and other structures of interest to help make up for some of these limitations. Performing these signal conditioning techniques in real time is the real strength of a DSP.

Image reconstruction is often the most acute bottleneck in a medical imaging system. A typical CT scan, for example, would involve the acquisition of many “slice” images of the region of interest. It is then up to the system to reconstruct the composite image from the slices. A multicore DSP can significantly reduce the time required for image reconstruction by parallelizing the reconstruction operations across multiple DSP cores, thus eliminating this bottleneck.

A multicore DSP also gives the system scalability, whereby existing image-enhancement techniques can be made more or less sophisticated by spreading the processing across multiple similar cores without impacting how long it takes for images to be processed and displayed.

In addition, the programmable nature of DSP cores makes them easy to upgrade when newer, more advanced imaging enhancement algorithms become available, thereby enabling equipment upgrades via software on existing hardware platforms.

Image display. A medical imaging system's back-end processing includes the actual presentation of images to the user as well as all of the operator interface requirements of the system. A multicore heterogeneous processor made up of a GPP core and a DSP core can work in concert with one another to provide the appropriate processing capabilities needed by each distinct function. Before the actual display of the images on a screen, the DSP core can perform many functions such as data interpolation, magnitude estimation, log compression, scan conversion and others.

At the same time, GPP cores such as those from ARM Ltd. can provide the functional equivalent of a PC processor – but at a fraction of the power consumption. Embedded ARM cores on average consume less than 2 watts of power, while the processors found in most PCs consume upwards of 50 or 60 watts. For portable power- and temperature-conscious medical imaging systems, savings of this magnitude are essential. The GPP core can also run a feature-rich operating system such as Linux or Windows CE, forming the basis for the system's operator interface and easing the system designer's task of developing differentiating and innovative features.

Today's multicore DSPs are full-featured SoCs and include a range of peripherals already integrated on-chip. These peripherals often include interfaces to Ethernet, storage devices, high-definition displays and miscellaneous connectivity. By integrating the control chips for these peripheral interfaces into one multicore SoC, both space and cost for the system are reduced.

Portable medical imaging systems face unique constraints. Portable systems by definition are small. As a result, real estate (for knobs, switches and other types of control mechanisms) is usually very limited. Programmable multicore SoCs allow system developers to design in intelligent controls that relieve operators from manually setting many imaging and measurement parameters.

So, for instance, an ultrasound imaging system set with a single selection for a cardiology diagnosis would automatically load in the parameters, algorithms and other required processing resources for this specific imaging application. Measurements relevant for blood flow velocity and power would be captured and displayed. This level of automation would also allow sophisticated medical imaging systems to be deployed in remote and rural areas where expert technicians are less available. Technicians in remote clinics could rely on the intelligence of the system itself to capture the appropriate images and measurements and send them to expert diagnosticians.

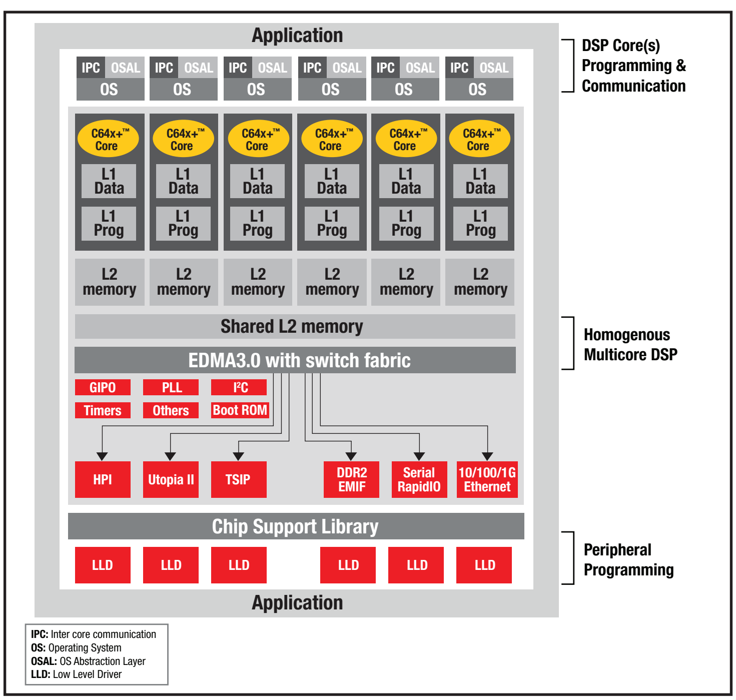
Putting multicore to work

Developing any sophisticated and complex embedded system such as a medical imaging system typically presents many challenges to the design team. Generally speaking, all embedded systems must meet critical performance needs while keeping within tight power budgets and size constraints. The customization of off-the-shelf hardware, which is usually inevitable, will come with its own cost constraints. Debugging and testing hardware and software is frequently difficult because of limited visibility.

The increased resources and, in particular, the presence of certain specialized capabilities in multicore processor solutions can help alleviate some of the challenges of embedded system design, but there are other complexities such as load balancing across cores, inter-core communication and shared resource management. Texas Instruments (TI) has more than a decade of experience with development and debugging tools and software frameworks that can simplify the integration of multicore processors into embedded systems in general – and medical imaging systems in particular.

To achieve optimal performance, designers need to carefully partition tasks so that the operation of a core can proceed with the least amount of dependency on the operation of the other cores. The data required for this processing should be available in local memory and usage of shared resources managed in a global fashion (i.e., across all cores). If this is done correctly, a system using a multicore processor has significant advantages over a system with multiple discrete processors. Access to data is faster, latency of communication across processing elements is lower, and bookkeeping overhead is minimized.

To facilitate development with multicore DSPs, TI has several multicore software frameworks and a robust set of debugging and profiling tools, as shown in Figs. 2 and 3.



▲ *Figure 2: Multicore software framework for the TMS320C6472 processor*

To allow software developers to focus on the critical problems of their application, it helps to have a software framework that provides both hardware abstraction as well as the middleware for common support tasks (e.g. intercore communication, DMA resource assignment, memory management, etc.). It is also essential that these software layers are optimized for the specific hardware platform so that they don't bog down the user application.

In the simple software framework described in Fig. 2, the programming of the processor core is abstracted by a real-time operating system that typically has a very small memory footprint, a scheduler with low latency task switching and efficient interrupt service routines. Peripherals are abstracted at two levels, either through a chip support library with raw register read/write functions or low-level drivers that support standard driver interface constructs (e.g. open, close, read, write, etc.). The intercore communication in this framework leverages the shared memory architecture of the TMS320C6472 device for fast, predictable communication; the management of DMA resources is provided via a software library. These services are thus readily available to the user application.

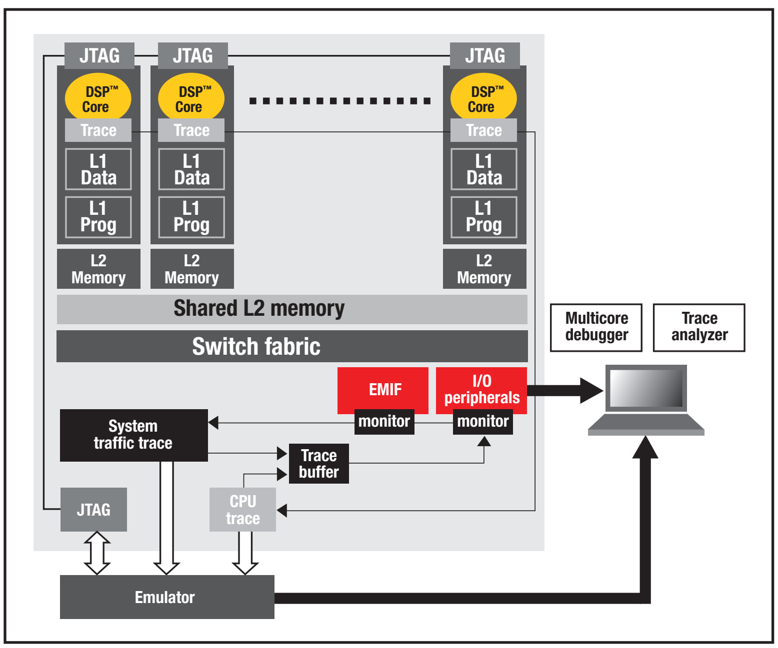


Figure 3: Multicore DSP debugging and execution profiling

Some key needs for multicore debugging include a system-level view of code execution across all the cores; coherent visibility across all memories (both shared and core-specific); and to be able to debug code on one core while the rest of the cores continue to execute normally. When optimizing the application, one may need to understand both average and peak loading of the cores, identify traffic bottlenecks or system deadlocks, and capture time-stamped statistics for events or I/O transactions. These multicore debugging and system execution profiling capabilities are well supported in TI's Code Composer Studio™ development tools and data analysis and visualization tool.

Multicore DSP solutions

For more than 10 years, multicore DSPs have shown their worth in a wide variety of applications across a range of industries. From wireless base stations to voice gateways, multicore homogenous DSPs have been the appropriate choice where compute-intensive signal processing is required in a limited power budget and confined physical space.

Heterogeneous multicore processors enable applications that require divergent processing capabilities for tasks that are fundamentally different in their processing needs.

This is not a one-size-fits-all approach to solving the complex signal processing needs of today's embedded systems, but rather offers medical imaging system designers a combination of attributes unmatched in the industry: low power, predictable real-time signal and data processing, a high level of integration to reduce system size and cost, and programmability to shorten product development time.

TI is making medical imaging development easy and affordable by offering the complete signal chain. Go to www.ti.com/medicalimaging to learn more and view TI's medical imaging resources, including:

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