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Distributed Embedded Computing in the Detection of Explosives

Analogic Corporation has developed the EXplosive Assessment Computed Tomography (EXACT™) scanner that is at the heart of an FAA-certified system used to detect explosives in checked luggage at airports. The scanner employs X-ray computed tomography (CT) to create a three-dimensional image of the entire contents of each bag and then automatically analyzes the data to locate explosives. CT image reconstruction resulting in ninety two-dimensional images per second is one of the major tasks in the scanner. The purpose of this talk is to show how the reconstruction is implemented by distributing the operations over fifty processors.

The EXACT uses SKYpack systems from SKY Computers in Chelmsford, MA, as the dedicated reconstruction computer. SKYpack is an application-specific repackaging of a standard 6U VME product originally developed for use on the DARPA SAST (Situationally Adaptive Sonar Technologies) program. It is a dual-use commercial-based application solution, used for critical explosive detection for Homeland Security and for Medical CT image processing.

In the EXACT scanner, each SKYpack uses one system processor, twelve RISC DSP processors, six SHARC DSPs (Analog Devices, Norwood, MA), and six application-specific ASICs. The scanner has two SKYpack computers, providing a total of fifty processing elements for image reconstruction. All processes run asynchronously and are data driven. Inter-processor coordination is achieved using semaphores. The loss of data is prevented by buffering mechanisms.

The X-ray data consists of helical cone-beam projections. The projection data rate is 6064 samples per view at 1080 views per second. Two X-ray energy spectra are used, one high energy and one low energy. The data is split into high and low energy views. Each set of views is sent to one SKYpack. Each SKYpack processes the data and generates 45 two-dimensional images per second.

Images are reconstructed from the projection data using an algorithm called Nutating Slice Reconstruction [1]. The algorithm converts cone beam data into fan beam data and then to parallel data. Successive image slices are created from overlapping data sets. The reconstruction task is partitioned into a series of smaller steps using a pipelined architecture [2].

In each SKYpack, eight processes running on eight RISC processors correct the input data for dark currents, gain non-uniformities and nonlinear effects. They also extract sets of one-dimensional fan beam projections from the cone-beam projections. Each cone beam projection contributes to 22 slices, so 22 slice buffers are stored in memory. This stage also performs some of the rebinning operations on fan beam data. Each of the 22 buffers is separately weighted and processed to obtain an intermediate result, hybrid parallel projections. Each cone beam projection is processed as above, and then discarded.

The next stage of processing, running on two RISC processors, converts the hybrid parallel projections into parallel beams suitable for back-projection.

The parallel beam data is delivered to six SHARC processors for high-pass filtering. Filtering is implemented with Fast Fourier Transforms. Twelve views are filtered at a time. Filtered projections are sent to six ASICs for back-projection, an operation that smears the projection into image space.

Nutated slices, which are non-parallel, are obtained as a result of back-projection. The nutated slices are interpolated to give slices that are all perpendicular to the axis of rotation at the next stage executed on one RISC processor. Post-processing and the delivery of the output slices are performed on another RISC processor.

Sequentially executed offline code was written to verify and validate the reconstruction software. The offline code was first verified using simulated data of known objects with known measurable properties. Once the offline code was validated, it was used to verify the online code by comparing intermediate results from each and matching them to within a specified tolerance.

A second subsystem consisting of four processors receives images from the scanner subsystem. The data is propagated through two paths that look for sheet and bulk explosives [3]. Each path uses detection and discrimination algorithms and connected components labeling. Other processes on the second subsystem carry out the functions of image display, archiving, communications and control of the scanner.

References

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