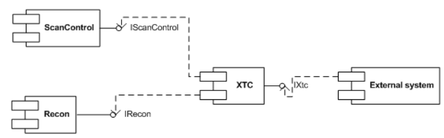
eXTernal Control (XTC): a flexible, real-time, low-latency, bi-directional scanner interface

J. Smink[1], M. Häkkinen[2], R. Holthuizen[1], S. Krueger[3], M. Ries[4], Y. Berber[4], C. Moonen[4], M. Köhler[2], and E. Vahala[2]
[1]Philips Healthcare, Best, Netherlands, [2]Philips Healthcare, Helsinki, Finland, [3]Philips Research, Hamburg, Germany, [4]IMF, Bordeaux, France

Introduction

There is a trend from using MR scanners purely for diagnostic radiology towards using them as a building block in larger systems in image guided interventions and therapy. Most of these systems are still in pre-development stage and require a flexible and fast prototyping environment. A typical interventional application integrates data from several sources and performs real-time image-processing prior to applying feedback to the procedure. Therapies involving moving organs have demanding requirements in terms of the latency of the feedback data, while others have far-reaching requirements on how to exert autonomous control over the scanner. This has lead to several approaches for an external application to control the scanner (1, 2). We have developed a new interface to the scanner which allows an external computer or a co-hosted application to control every scan protocol safely. The interface provides fast, low latency, low jitter access to output data, and flexible access and update of scan parameters during scanning. Applications have been developed in MR-guided HIFU and MR-guided EP. An open source development environment has been made available for pre-clinical applications

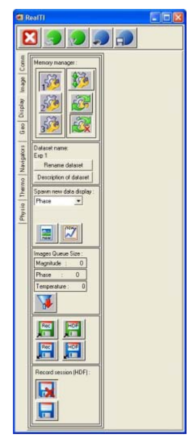


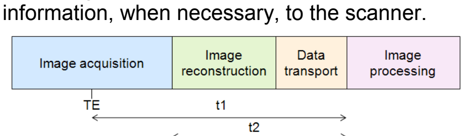
Methods

A new scanner interface, denominated XTC (eXTernal Control), was integrated into the Philips scanner software. It communicates with the reconstruction and scanner processes on the host and interfaces to a networked application using a minimalistic CORBA (3) interface which uses TCP/IP as the transport layer. CORBA was chosen for its performance, reliability, platform independency and its ability to process large amounts of data with minimum overhead. Each CORBA message consists of a hierarchical attribute collection, i.e. a recursive structure of primitive attributes and sub collections. Attributes are identified with UUIDs (4) to facilitate independent extensions and development. Messages allow to carry raw data for external real-time reconstruction e.g. on GPU-based platforms, and also reconstructed image data, navigator data, physiology sensor data, device tracking positions and meta-data containing details of scan protocols. The external process applies received messages to e.g. update the scan geometry, enable/disable device tracking or to start/stop a scan. Scan protocols need to be prepared and validated (safety) at the scanner in an ExamCard before the external computer takes over control but the order, execution and repetition of the scans can be controlled externally.
The performance of the XTC connections in terms of latency was measured with dynamic single shot EPI scans and hardware logic-signals to measure the timing of the processes. A simulator was developed for rapid prototyping without scanner hardware access. The simulator uses a DICOM dataset and performs multi-planar reformats based on the geometry messages. It also simulates device tracking functionality.

Results

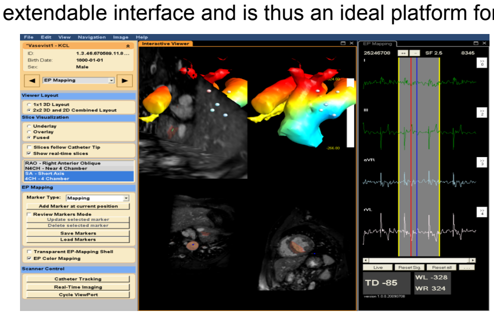
XTC has been successfully used in four applications. In the Philips Sonalleve MR-HIFU platform, CE approved for the ablation of uterine fibroids (5), the planning console selects remotely the required scan protocols, downloads DICOM datasets for planning of subsequent scans and HIFU therapy, starts and stops dynamic scanning, retrieves reconstructed image data as they become available and calculates temperature maps from the said data. The second example is the RealTI open source environment available for Windows and Linux. A graphical user interface is developed in IDL and a wrapper layer is made in C++. The environment forms a modular framework and is now used for MR-guided thermotherapy (6) and local drug delivery applications and gene expression. Available modules include motion tracking, thermometry and T1 and T2*-calculation. The third example is the MR-guided EP project, in which the MR-EP application integrates MR-images from the scanner with cardiac EP-data from an EP-recorder (7). The last example is the XTC-datadumper, written in C#, which can be used as an example project for other stand-alone prototype applications. It runs on an external windows PC and dumps all retrieved images and other data source in files on the local hard disk. It reads continuously local geometry update files and sends this information, when necessary, to the scanner.
The total latency (t1) of images in single shot EPI scans with 128 matrix and TE 50ms was 59.7 ms of which 9.7±1 ms is due to reconstruction and data transport (t2). For a 256 matrix, the TE was 150 ms and latency t1 was 171.3 ms of which t2 was 21.3±1 ms.

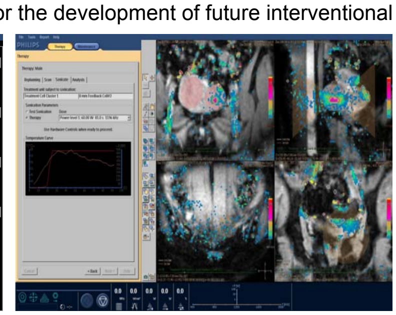




Discussion

XTC is applicable to all scan protocols; the only restriction is a slight increase in the minimum echo time. Since the geometry is allowed to change in run-time, the gradient waveforms are prepared for the worst-case orientation in order to not exceed slew rate limitations. For safety reasons SAR is also controlled on-line by the scanner. Unsafe externally controlled changes to the timing or RF usage of the scan will be run-time detected, notified, and the scan will be paused until the error condition is removed. Since the transport layer of XTC is based on TCP/IP, the data distribution is fully routable and compatible with any state-of-the-art gigabit network infrastructure. The implementation of XTC is very similar to the standard Interactive scan mode of most vendors, which means that extensions like on-the-fly modifications of pre-pulse delays, repetition times etc. are easily implemented. XTC offers safety, performance and flexibility based on a well defined, extendable interface and is thus an ideal platform for the development of future interventional and therapeutic MR applications.





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