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Published in:
Proceedings of 2023 IEEE International Ultrasonics Symposium

Publication date:
2023

Document Version
Peer reviewed version

Ten-minute Continuous Acquisitions with the Verasonics Vantage Research Scanner

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Abstract— **Functional imaging and super-resolution imaging are promising research areas of medical ultrasound. For the purpose of tracking physiological changes and micro-bubbles, they require continuous data acquisition for minutes. One flexible and mobile research scanner that can be used for that purpose is the Verasonics Vantage, which however has a hardware limitation of approximately 132,000 emissions per data acquisition using the stock software library. Using an emission rate of 5 kHz gives an acquisition time of only 26 seconds, which is insufficient. This paper presents a technique for overcoming this limitation, achieving long acquisitions where the scan duration is limited by the computer RAM only. The technique has been already routinely used for 10-minute in-vivo scans of exposed rat kidneys, resulting in micro-bubble tracking maps for super-resolution imaging.**

I. Introduction

Functional imaging [1] and super-resolution imaging [2], [3] are quickly evolving research areas of medical ultrasound. For the purpose of tracking physiological changes and micro-bubbles, they require continuous data acquisition for minutes. One research scanner that allows developing new imaging modalities and is mobile, therefore suitable for use in clinical trials, is the Verasonics Vantage (Verasonics, Inc., Kirkland, WA 98034, USA) [4]. It consists of a front end and a host computer (PC), connected by data cable. The front end contains all transmit and receive amplifiers, analog-to-digital and digital-to-analog converters, programmable logic devices to perform the transmit and receive, and buffer memory and logic to perform data transfer to the PC. The host computer is a standard PC, thus presenting a straightforward path for upgrade/expansion of the RAM for storing ultrasound echo data. The front end, though, has a hardware limitation of 132 000 emissions per scan setup, which for an emission rate of 5 kHz gives a scan duration of only 26 seconds. This paper presents an approach to overcome this limitation and enable long acquisitions. A description of the default data acquisition algorithm is presented below, followed by a description of a proposed new mechanism.

II. Operation principles

A. Default data transfer mechanism in the Verasonics Vantage scanner

The setup and control of the scanner is performed in MATLAB (Mathworks Inc, Natick, MA, USA). The data transfer from the scanner front end is organized as a series of direct memory access (DMA) transfers, each of size up to 2 GB, to the computer RAM. An ultrasound image frame, consisting of 30 emissions and using 128 elements in receive for duration of 200 microseconds, will generate $30 * 128 * 200.10^{-6} * 62.5.10^{6} * 2 = 96$ MB of data (for 2 bytes per sample, 62.5 MHz sampling rate). Using a large block size is critical for achieving high average throughput, and in this case it can be achieved by replicating the frame 20 times per DMA transfer. During a data acquisition, the DMA areas in the PC RAM are filled up one by one with incoming data, then the acquisition stops, and the data is transferred out of the DMA areas to a MATLAB array. This mechanism is illustrated in Fig. 1. The theoretical achievable throughput is 4.4 GB/s for 128 active channels, and 6.6 GB/s for 256 active channels, and is limited by the hardware architecture of the front end logic and the data interface.

Since only DMA transfers are done during acquisition, there is minimum interaction/influence by the operation system, thus the acquisition reliability is high. Due to this design choice, there are downsides also: long acquisition preparation times, as several 10s of GB need to be allocated for DMA areas before every long (within the limitations) scan, and a long wait time after a measurement, as the data is copied out of the DMA areas and into the MATLAB array (which is actually created when the copying into it starts, due to the MATLAB memory management policies). The rate of reserving RAM for the MATLAB array and the DMA blocks is estimated to be around 1 GB/s. For an acquisition of size 80 GB, that means an 80 s waiting time before acquisition and 80 s waiting time after acquisition.

B. Modification for long data acquisitions

An acquisition setup can be reused in a loop, but any DMA-transferred data must be copied away before a new data block arrives to the same memory location. For that purpose, a fast copy routine has been implemented in C and included in a MATLAB library, to be called by the Vantage software at the end of each DMA transfer. The mechanism is illustrated in Fig. 2.

The DMA areas are created by the Vantage software library to accommodate data from either 128 or 256 channels, depending on the transducer definition. In the default data transfer mechanism, these are copied without modification to the MATLAB array. Thus, when the actual number of

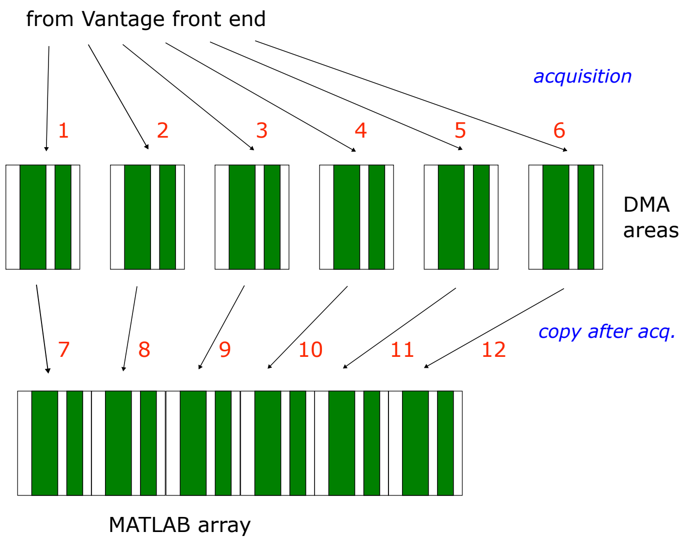

Fig. 1. Verasonics Vantage data transfer mechanism. The DMA areas in the computer RAM are filled with data sequentially, the acquisition is then stopped, and their content is then transferred to a Matlab array. Green blocks denote actually used RAM area (with non-zero data). The red numbers indicate the order of execution of the data transfers.

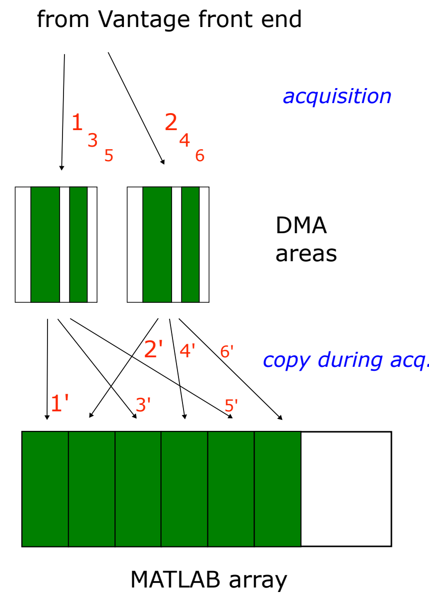

Fig. 2. Modified data transfer mechanism. Immediately after a DMA transfer is finished, a copy operation to the Matlab array is started. Green blocks denote actually used RAM area (with non-zero data). The red numbers indicate the order of execution of the data transfers.

transducer elements is lower than 128 or 256, or only a sub-aperture is used in receive, a large part of the MATLAB array contains zeros. The new copy routine performs channel reduction/remapping, to avoiding wasted memory for the unused channels when only part of the elements/channels are used in receive, thus enabling longer data acquisitions to be made. The copied data is stored in a single large one-dimensional MATLAB array, which is created once per MATLAB session before any measurements take place, and is reused for all subsequent acquisitions of any kind performed during the session.

C. Consequences of using a non-real-time operation system

Due to the non-real-time nature of the operation system (OS) on the host computer, the copy operations do not finish as soon as expected based on simple throughput calculations. A double-buffer copy (one DMA area being filled in while the other is being rearranged/copied out) is therefore not immune to data corruption due to overwriting.

An experiment with ten 1.8 GB data blocks to be copied/rearranged, with copy operations being started at intervals of 0.5 seconds, results in the timing map shown in Fig. 3. On that figure, the circles indicate the timing of the copy start of individual sub-blocks (64 of them) inside a 1.8 GB block. No other user program was running on the computer, only Linux OS background processes and the Ubuntu Linux user graphical user interface. The copy/rearrange routine itself achieves in tests a throughput of 16 GB/s, therefore each individual copy operation should finish in $1.8/16 = 0.1125s$, but that does not occur in practice. This test indicates that at least 8 buffers are necessary, so that a DMA transfer to a RAM area does not start before the previous copy process out of that area is finished.

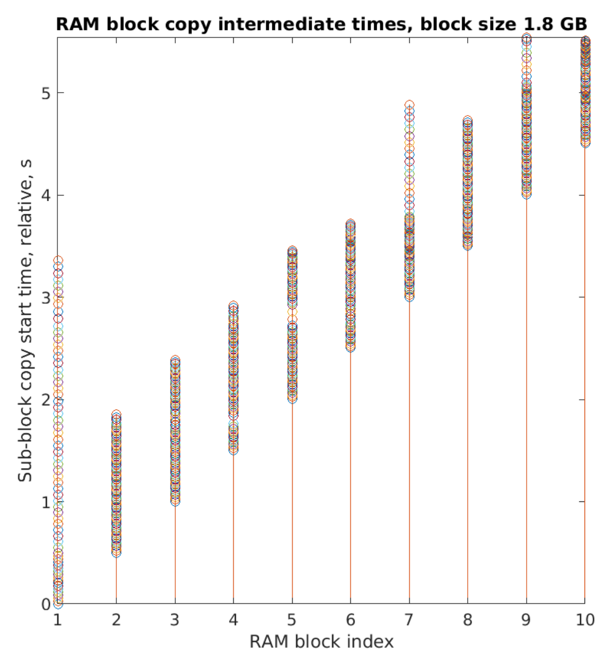

Fig. 3. Copy progress for 10 data blocks of 1.8 GB each. The circles mark the intermediate copy start times of sub-blocks (64 in a block).

During actual use of the scanning software, where also acquisition is running (DMA transfers are being performed) and a scan program GUI is being handled, even larger number of DMA buffers is necessary for achieving reliable error-free acquisition. Acquisition reliability tests have been performed, relying on the time stamps generated by the Vantage front end, inserted for every channel and emission in the sampled data. The integrity of the data in the MATLAB samples array is confirmed when all channel data time stamps per emission are the same, and the time step between the time stamps of consecutive emissions is equal to the user-programmed period between the emissions.

An extra step that was necessary was the reduction of priority (increasing the Linux OS ”nice” parameter to the value of 10) of the MATLAB Java helper processes in Linux. These handle the GUI elements in MATLAB, so the interface became a bit less responsive.

III. Results

In a host computer with 512 GB RAM, the size of the samples array in MATLAB can be up to 460 GB, allowing for more than 10-minute scan duration in a micro-bubble tracking setup. A 12-buffer setup provides error-free acquisition, and a reliable throughput of up to 3.0 GB/s can be maintained throughout a measurement. The proposed data acquisition mechanism has been successfully used in multiple in-vivo measurements of rats [5], [6].

IV. Discussion

The proposed method achieves the goal of enabling long acquisitions with relatively little waiting time before (reserving RAM for 12 DMA buffers instead of, f.ex., 45) and almost no delay after them, as the last of the copy processes finish nearly immediately after a scan. The drawback of the new mechanism is reduced maximum throughput, which however does not affect the long acquisitions, which are optimized with the finite RAM space available in mind, this running at well below the highest possible data rate.

V. Conclusion

A data transfer mechanism for the Verasonics Vantage scanner has been developed, which allows long acquisition times to be used. This is essential for tracking micro-bubbles or physiological changes in living tissue. The mechanism has been successfully used for 10-minute in-vivo scans of rats and will be employed in future in-vivo scans of animals and humans.

Acknowledgment

The work was financially supported by ERC synergy grant 854796 - SURE from the European Research Council.

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