Hardware accelerated image processing to enable real-time adaptive radiotherapy

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Introduction

The quality of organ delineation and tumour outlining in radiotherapy is constrained by organ motion and deformation occurring between the acquisition of CT and MR images used to plan the treatment, and the time at which the treatment is delivered. An example illustrating these changes in a prostate cancer patient is shown in Figure 1. MR images, though unnecessary for radiotherapy, allow better organ delineation than CT.

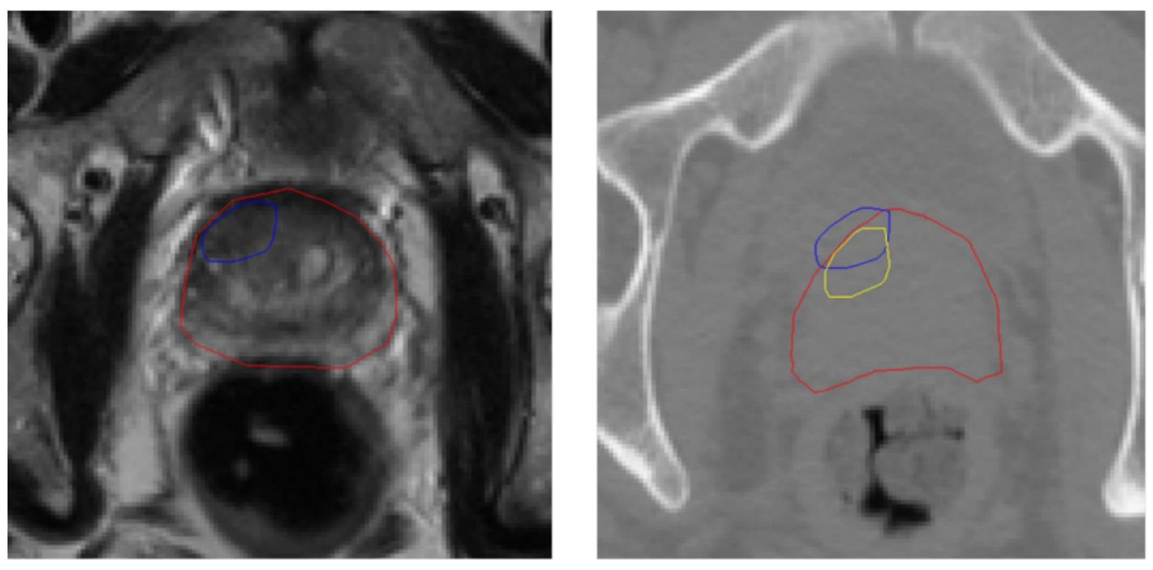

Figure 1: MR image (left) and CT image (right) of a prostate cancer patient acquired at different times. The red contour shows the outline of the prostate gland, the blue contour shows the position of the focal lesion as identified from the MR image, and the yellow contour shows the suspected position of the focal lesion on the CT image[1].

Adaptive radiotherapy uses image data acquired at the time of treatment to adapt the original treatment plan to match the current patient anatomy. Currently, the image processing and dose calculation algorithms required to perform this plan adaptation cannot be executed in a clinically acceptable timeframe. Hardware acceleration has the potential to speedup these algorithms, making real-time adaptive radiotherapy a clinical possiblity[2].

Hardware acceleration is a technique where an algorithm is implemented using hardware that is better suited to the specific algorithm than more general purpose processors in order to reduce the execution time of the algorithm. This can be achieved using Field Programmable Gate Arrays (FPGA), which are devices consisting of reconfigurable hardware, allowing their function to be customised for a specific application. A schematic diagram of FPGA fabric is shown in Figure 2. These devices have been shown to be able to accelerate image processing algorithms pertinent to adaptive radiotherapy[3]. They also allow processing to be performed locally rather than remotely on a "cloud", thus avoiding data issues in large NHS hospitals.

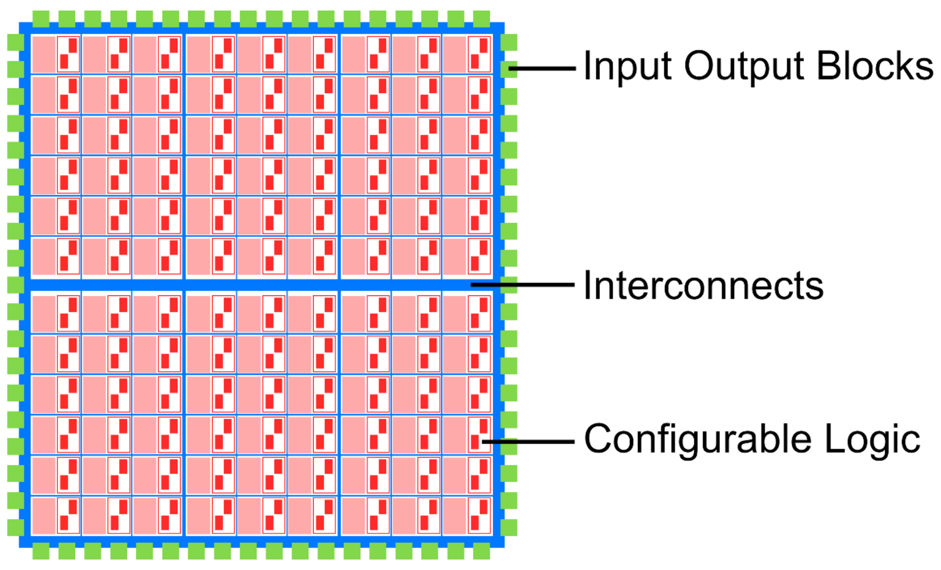

Figure 2: Schematic diagram of FPGA fabric

Methodology

A global thresholding algorithm based on Otsu's method[4] combined with a three dimensional mean filter was used to segment a series of 4D CT images of a Modus QUASAR respiratory motion phantom into three unique classes. A Xilinx Zynq Z-7020 device consisting of a dual-core ARM Cortex-A9 central processing unit (CPU) coupled to an 85,000 logic cell FPGA was used to accelerate the algorithm. The threshold generation and mean filter portions of the algorithm were implemented in the FPGA fabric of the Zynq device, as shown in Figure 3.

The execution time of the implementation utilising the FPGA fabric was compared to a software implementation of the same algorithm running on an ARM Cortex-A9 CPU and an Intel Core-i5 CPU. The Intel processor was selected as being representative of the type of processor currently routinely available local to treatment delivery.

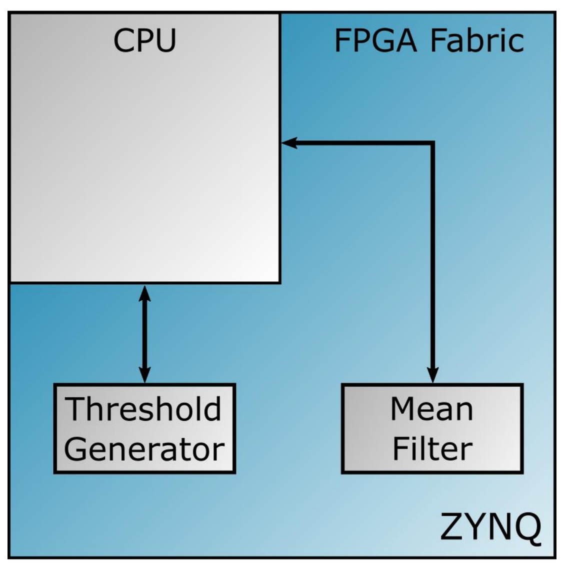

Figure 3: Schematic diagram of hardware accelerated segmentation algorithm

Results

Table 1: Algorithm execution times

Implementation	Execution Time (ms)
Hardware Accelerated	14.8
ARM Cortex-A9	885.0
Intel Core-i5	17.0

Table 1 shows the execution times of the implementations. The hardware accelerated implementation was found to execute nearly sixty times as fast as the non-accelerated algorithm. It was also found to run around 14% faster than on the more powerful Intel Core-i5 CPU. Figure 4 shows an example of the segmentation results.

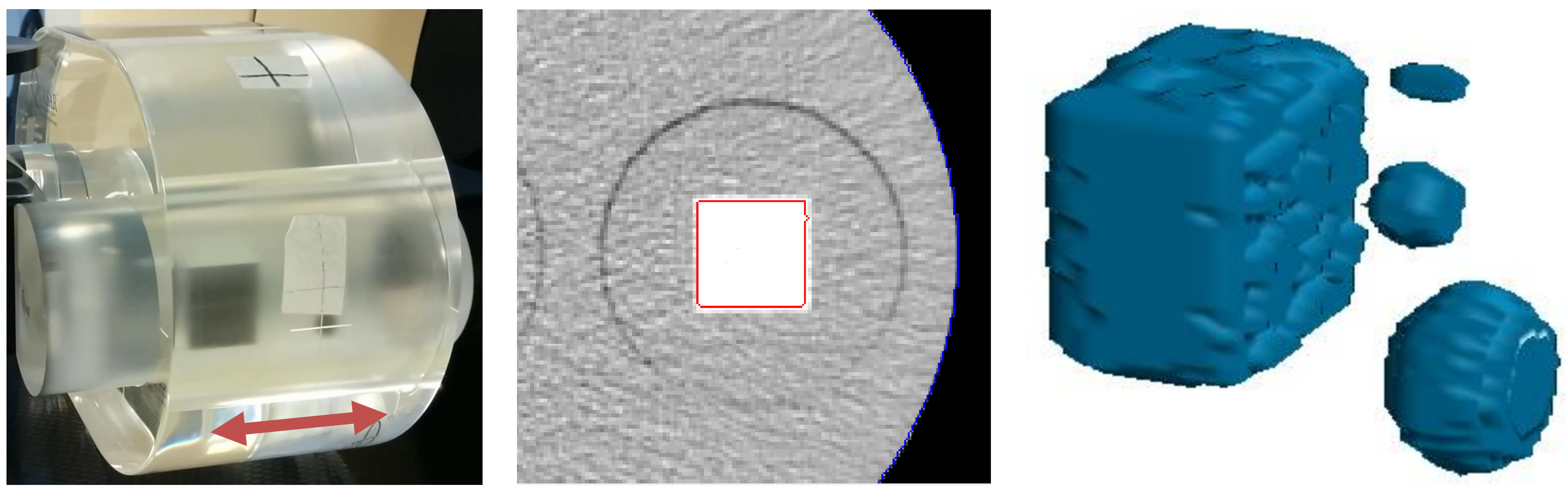

Figure 4: Phantom with arrow indicating direction of motion of imaging insert (left). CT slice of phantom with boundaries between segmented classes marked by the red and blue contours (centre). 3D rendering of one of the segmented classes (right).

In the algorithm presented here the overhead of transferring data to the hardware represents a significant proportion of the algorithm execution time. It is anticipated that greater acceleration will be possible for algorithms with greater computational complexity (next stages in the research work) because the data transfer overhead will represent a smaller proportion of the overall execution time.

Future Trends

The requirement for fast processing in radiotherapy is likely to grow as the amount of data available to more accurately guide treatment increases through the use of techniques such as 4D CT and image-guided radiotherapy. FPGA have been shown to be effective at accelerating certain algorithms required for real-time adaptive radiotherapy, however, more research is required to establish which will execute faster on other types of hardware, such as CPU and graphical processing units (GPU). It is likely that heterogeneous computing platforms, composed of a mixture of hardware architectures will be used in the future implementation of real-time adaptive radiotherapy.

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