Ultrasound computer assisted screening for early diagnosis of prostate cancer

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IICT
Cancer of the prostate (PCa) is one of the most important medical problems facing the male population.

- In Europe, PCa is the most common solid neoplasm, with an incidence rate of 214 cases per 1000 men.
- PCa is currently the second most common cause of cancer death in men.
- Since 1985, there a slight increase in most countries in the number of deaths from PCa, even in countries or regions where PCa is not common.
- About 15% of male cancers in developed countries are due to PCa.
In Bulgaria PCa rate remains stable and even increases in the last years, due to the mass PSA screening of men over 50. The wide distribution of modern ultrasound devices in the country, also contributes for earlier diagnosis of PCa.
“One of the biggest barriers to effective treatment of prostate cancer is that we haven't had good ways to identify the cancer with conventional imaging, and so we have **had to make important decisions without solid information.**”

Dr. Reiter, Director of UCLA Prostate Cancer Program (Spring 2009, Los Angeles, CA, USA).
The **main goal** of the newly developed software, presented in this paper, is improvement of the diagnostic rate by improving the image of the ultrasound scan, **by the supercomputer clarifying**. This will contribute for earlier diagnose of “smaller”, **clinically insignificant**, or even “obscured” prostate lesions.
The most appropriate screening modalities for prostate cancer detection are:

- Digital Rectal Examination (DRE);
- Prostate Specific Antigen (PSA) test;
- Ultrasound screening;
- Pelvic computed tomography (CT) scan;
- Magnetic Resonance Imaging (MRI);
- Biopsy test.
DRE is the most common inexpensive test for prostate cancer detection. A skilled physician can detect only tumors in advanced stages, which are palpable.

The probability of correct detection is usually low. The use of DRE has never been shown to prevent prostate cancer deaths when used as the only screening test.
PSA test is regarded as one of the most successful markers for early detection of prostate cancer.

The PSA test measures the blood level of prostate-specific antigen, an enzyme produced by the prostate. The average cancer detection rate is about 66%. The most important problem in application of PSA test consists of that malignant prostate cells produce less free PSA than hyperplasia prostate.
Ultrasound screening is an inexpensive and non-invasive test. Ultrasound test produces images of the tissue of interest using sound waves and their reflection from different layers in the body. It committed in two modes – abdominal and transrectal.

Abdominal ultrasound test is the most usual mean for the urologists today, but it gives prostate image in a smaller scale in comparison with TRUS, where prostate is displayed in details.
Pelvic **computed tomography** scan is recommended usually to be used to detect enlarged pelvic lymph nodes or in cases where the available predictive information indicates a possible lymph node involvement.

**MRI** is an expensive hardly accessible test for prostate cancer detection.

**The biopsy test** is the surest test to obtain accurate results. It is not patient friendly – it is **invasive** procedure. The physician usually has to take 13-15 probes, in some cases it may be more than 20.
From the analysis above, it is clear that a diagnostic tool for detecting the suspicious regions is needed. It will minimize the invasive process of biopsy or even remove it at all, if the diagnostic results of this tool are credible.
Where we are?

Over the past 5 years many laboratories and teams made efforts to create such a diagnostic tool. A new term “histoscanning” was introduced and more than 50 papers and reports were published.

**Prostate HistoScanning™** is a tissue characterization technology developed to differentiate, characterize and visualize prostate tissue.

**In Bulgaria** - there are no histoscanning systems in use.
The most important features of the developed package:

- The input information is coming mostly from abdominal images, regularly used in mass screening;
- The system may be used also for TRUS images, which are more informative.
- The output images are available to physicians in a convenient environment. We rely on the physician knowledge and experience to fuse them and to summarize the results.
- Parallel processing is used to create images in near real time.
Although its attractiveness, the ultrasound examination of the prostate is not 100% solution of the carcinoma detection.

Carter et al were the first to suggest a relative lack of sensitivity with TRUS when they observed that only 54% of carcinomas identified on the nonclinically suspicious side of the prostate could be visualized with ultrasound.

Another study found that in radical prostatectomy specimens, only 36% of nonpalpable tumors were visualized on ultrasound.

Others have also reported that up to 40% of prostate cancers are isoechoic on ultrasound and therefore "invisible" to TRUS.
How to process images

Usually, the normal prostate gland has a homogenous, uniform echo (isoechoic) pattern. A PCA may take on unique ultrasound findings. Most ultrasound-detected lesions found to be carcinoma are described as hypoechoic regions with irregular borders. However, this is not a rule.

It was reported by Lee et al, that 70%-80% of prostate cancers arise from the peripheral zone of the prostate, on the contrary of transition zone, which is the site of the location of benign prostatic hyperplasia.
The transition zone becomes moderately **hypoechoic** in comparison with the central and peripheral zones. The highest predictive values for prostate cancer are seen in **hypoechoic lesions** that are well defined and are **larger than 1 cm**.

However, **not all hypoechoic regions in the peripheral zone are prostate cancer**. Potential hypoechoic lesions also include **prostatitis, prostatic infarction, dilated glands, smooth muscle bundles, scarring, and prostatic intraepithelial neoplasia**.
The analysis shows, that effective image processing algorithms have to reduce the specific for ultrasound images noise, discover hypoechoic regions in the peripherial zone, segment any irregularity, asymmetries and extensions and detect fields with higher blood flow.
The methods for image quality improvement can be divided into four parts:

- Filtering
- Multi-level segmentation
- Texture analysis
- Doppler image segmentation
Filtering procedures:

The most appropriate algorithms for noise reduction are smoothing filters.

The linear filters suppress pixel noise but have poor edge-blurring effect.

The nonlinear filters are especially chosen to preserve sharp edges simultaneously smoothing the surfaces.

Some of the available filters are: adaptive nonlinear Gaussian, anisotropic diffusion, combined stick filter, Kuwahara(1,2,3) and others. The most promising results were received for the images, processed by nonlinear Gaussian and dual tree complex wavelet filters.
Multi-level segmentation

Intends to differentiate the areas with different intensities.

Two algorithms were developed:
- Fast Otsu algorithm;
- LMQ (Lloyd-Max Quantizer) algorithm.

The problems to be solved:
- Suitable choice of the number of thresholds;
- Threshold’ values determination.
Texture analysis

Detects irregularities and anomalies in the prostate image on the base of automatic description of particular region.

The so-called co-occurrence matrices are used. The analysis allows us to evaluate a number of coefficients, which characterize the texture of the analyzed image. The received values are deterministic, image dependent only and are not influenced by personal assessment. The image is segmented in the space of these parameters, using clusterization technique.
Doppler image segmentation

The proposed algorithm separates the areas of increased blood flow in the Doppler or Power Doppler images.
Program realization

The main goal of the developed software package is to **enhance mass screening**. An appropriate engineering solution requires to be used an **affordable** hardware platform.

We choose multicore laptop with NVIDIA GPU supporting CUDA.

The program package is realized on MATLAB R2011a, using Parallel Computing Toolbox.
System architecture
The developed program works in **two modes**.

The **first mode** provides a convenient interface for **algorithm’s parameter tuning** and **output image selection**.

This first mode is used by **physicians** and **program developers simultaneously**.

The goal of the cooperative efforts is to define the best methods, tune their parameters and select the most promising/informative output images.
Dialog window of the program interface with selected ROI
The second mode of the program has been developed for the case of mass screening.

- The physician operates with medical ultrasound system and takes images from the observed prostate;
- The additional image processing is activated by pressing of a programmed button;
- The communication and processing program activates automatically;
- A plethora of images are produced in near real time;
- The physician takes visually reassured decision.
Parallel realization 1

The filtering, segmentation and texture processing are time consuming.

To speed up the calculations a parallel version is developed.

The tasks are differentiated by the used methods and design parameters of the methods for filtering and segmentation.
Parallel realization 2

Parallel Computing Toolbox™ solves computationally-intensive problems using multicore processors, GPUs, and computer clusters. High-level constructs like parallel for-loops, special array types, and parallelized numerical algorithms—let you parallelize MATLAB® applications without CUDA or MPI programming.
Parallel realization 3

Parallel for-Loops (parfor) - Applicable in two cases:

- Many iterations - a sweep might take a long time because it comprises many iterations, but each iteration by itself might not take long to execute.
- Long iterations - a sweep might not have a lot of iterations, but each iteration could take a long time to run.
Parallel realization 4

Classification description of loop variable:

- **Loop** - Serves as a loop index for arrays;
- **Sliced** - An array whose segments are operated on by different iterations of the loop;
- **Broadcast** - A variable defined before the loop whose value is used inside the loop, but never assigned inside the loop;
- **Reduction** - Accumulates a value across iterations of the loop, regardless of iteration order;
- **Temporary Variable** - created inside the loop, but unlike sliced or reduction variables, not available outside the loop.
A distributed job is one whose tasks do not directly communicate with each other. The tasks do not need to run simultaneously, and a worker might run several tasks of the same job in succession. Typically, all tasks perform the same or similar functions on different data sets in an embarrassingly parallel configuration.
Block-diagram of the parallel algorithm

Ultrasound image - ROI

Filtering part

Filter 1
(Gauss)

Filter 2
(Wavelet)

Filter n
(Kuwahara)

Segmentation part

Segmentation 1
(OTSU)

Segmentation 2
(LMO L=5)

Segmentation n
(LMO L=4)

Examination and decision making
Parallel MATLAB code

```
jm = findResource('scheduler','configuration','local')
job1 = createJob(jm)
createTask(job1, @ParProc, 1,{{pArr1}{pArr2}{pArr3}}); submit(job1)
waitForState(job1)
results = getAllOutputArguments(job1);
```

- **findResource** – creates an object representing the local scheduler.
- **createJob** – creates a job in the scheduler's data location.
- **createTask** – create task with specified procedure and corresponding input data.
- **submit** – the job1 is submitted (queued) for running.
- **waitForState** – wait for job finish;
- **getAllOutputArguments** – get the results.
Results of parallel MATLAB implementation on PC

Except the original ROI image, the results of three different combinations of filtering and segmentation are presented:

1. Gaussian filter with number of iterations \(N=1\), window size \(nw=3\) and segmentation method LMQ with number of levels \(L=4\);

2. Gaussian filter with number of iterations \(N=5\), window size \(nw=5\) and segmentation method LMQ with number of levels \(L=5\);

3. complex dual tree wavelet filter and segmentation method LMQ with number of levels \(L=5\);
Results from the proposed software tool

- **a)** Original ultrasound image
- **b)** Processed image (Gaussian $N=1$, $nw=3$, $LMQ\ L=4$)
- **c)** Processed image (Gaussian $N=5$, $nw=5$, $LMQ\ L=5$)
- **d)** Processed image (Wavelet C2D, $LMQ\ L=5$)
Some results

<table>
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<tr>
<th>Task parameter</th>
<th>( t_1 ) [s]</th>
<th>( t_2 ) [s]</th>
<th>( t_3 ) [s]</th>
<th>Total Serial [s]</th>
<th>Parallel [s]</th>
<th>( K = \frac{\text{Total}}{\text{Serial}} )</th>
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<tr>
<td>( N=1, n_w=3,5,7 )</td>
<td>2.25</td>
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<td>10.27</td>
<td>25.17</td>
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</tbody>
</table>
Future work for parallel implementation on PC

Due to inequality in computer resources of the parallel tasks it will be promising to use GPU with CUDA to shortened the most time-consuming algorithms like texture analysis, multi-step filtering, etc.
Conclusions:

1. A program tool for ultrasound image processing is proposed for computer assisted medical diagnosis.

2. Parallel implementation using MATLAB Parallel computing toolbox is realized. The parallelization speeds up the time consuming filtering and segmentation process and thus makes it possible for mass screening.

3. Although the ultrasound examination does not guarantee 100% carcinoma detection, the proposed tool will support visual reassurance for treatment decision-making process and as a final result a reduction in mortality due to prostate cancer will be achieved.
Questions?