Ultrasound Computer Assisted Screening for Early Diagnosis of Prostate Cancer

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Key Words: Computer assisted screening; ultrasound imaging; image processing; parallel algorithms.

Abstract. The main goal of the tool proposed in this paper is diagnostic quality enhancement by improving the images of the ultrasound scan using parallel computer processing. Many advanced algorithms for speckle noise filtering, image segmentation and texture analysis are implemented and coded to run in parallel. The physician receives several output images with outlined regions where different anomalies were detected. The coincidence of the regions indicates higher probability of prostate cancer. This will contribute for earlier diagnose of "smaller", clinically insignificant, or even "obscured" prostate lesions and provides visual reassurance for treatment decision-making process.

Introduction

The prostate cancer (PCa) is now recognized as 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, outnumbering lung and colorectal cancer. Furthermore, PCa is currently the second most common cause of cancer death in men. In addition, since 1985 in most countries there has been a slight increase in the number of deaths from PCa, even in countries or regions where PCa is not common [1,2,3,4].

The prostate cancer affects elderly men more often than young men. It is therefore a bigger health concern in developed countries with their greater proportion of elderly men. Thus, about 15% of male cancers are PCa in developed countries compared to 4% of male cancers in undeveloped countries. It is worth mentioning that there are large regional differences in incidence rates of PCa. For example, in Sweden, where there is a long life expectancy and mortality from smoking-related diseases is relatively modest, PCa is the most common malignancy in males, accounting for 37% of all new cases of cancer in 2004 [5].

Decreased mortality rates due to PCa have occurred in the USA, Austria, UK and France, while in Sweden, the 5-year survival rate has increased from 1960 to 1988, probably due to increased diagnostic activity and greater detection of non-lethal tumors. However, this trend was not confirmed in a similar study from the Netherlands. The reduced mortality seen recently in the USA is often attributed to the widely adopted aggressive screening policy, but there is still no absolute proof that prostate-specific antigen (PSA) screening reduces mortality due to PCa.

In Bulgaria, the 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.

The main goal of the newly developed software, presented in this paper, is improvement of the diagnostic rate by improving (refinement of) the ultrasound scan image ,by the supercomputer clarifying. This will contribute for earlier diagnose of "smaller", clinically insignificant, or even "obscured" prostate lesions.

TRUS (TransRectal UltraSonography) of the prostate, first described by Watanabe and colleagues (1968), expanded to routine clinical use with improvements in ultrasound technology and the introduction of the TRUS-guided systematic sextant biopsy protocol by Hodge and associates.

Concurrent with improved biopsy techniques, the use of PSA screening increased the number of men undergoing early prostate cancer screening and prostate biopsy with estimates as high as 800,000 biopsies annually in the United States alone. Given the prevalence of prostate cancer and the frequency with which TRUS-guided prostate biopsies are performed, significant efforts have been focused on determining the appropriate indications for biopsy and the ideal technique to perform imaging and biopsy of the prostate.

TRUS technology has become a mainstay of many image-guided prostate interventions, including prostate biopsy, brachytherapy, cryotherapy, and high-intensity focused ultrasound (HIFU), as well as being used in the evaluation of appropriate patients for treatment of benign prostatic hyperplasia (BPH). Fiducial gold seeds are being placed under ultrasound guidance to verify and correct the position of the prostate during megavoltage irradiation (Dehnad et al, 2003).

The primary endpoint of PCa screening has two aspects:

1. Reduction in mortality from PCa. The goal is not to detect more and more carcinomas, nor is survival the endpoint because survival is strongly influenced by lead-time from diagnosis.

2. The quality of life is important as expressed by quality-of-life adjusted gain in life years (QUALYs). The prostate cancer mortality trends range widely from country to country in the industrialized world.

Motivation for Computer Assisted Ultrasound Screening Used in Prostate Cancer Diagnosis

The early detection of prostate cancer is of crucial importance for its successful treatment. "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" said Dr. Reiter, Director of UCLA Prostate Cancer Program (Spring 2009, Los Angeles, CA, USA). The most appropriate screening modalities for prostate cancer detection are the Digital Rectal Examination (DRE), the Prostate Specific Antigen (PSA) test, the Ultrasound screening, the Pelvic computed tomography (CT) scan, the Magnetic Resonance Imaging (MRI), the 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. The 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 the PSA test consists of(is based on the fact) that malignant prostate cells produce less free PSA than the hyperplasia prostate. There is a large region where a differentiation between tumor and benign hyperplasia has to be additionally performed. The ultrasound screening is an inexpensive test, performed in two run modes – abdominal and transrectal. The ultrasound test produces images of the tissue of interest using sound waves and their reflection from different layers in the body. The 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 the prostate is displayed in details. The 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 today to obtain accurate results. There are several problems with the application of the test. The first and the most serious one is that it is not patient friendly – it is an invasive procedure. The physician has to take probe in a determined in advance zone of interest. The minimal number of probes to be taken is 3-5, but usually their number reaches 13-15 and in rare cases it may be more than 20. The doctors take more probes to increase the probability of detection of the carcinoma, but the great number is not the best solution. Something more, biopsy may initiate carcinoma growth process and has many contraindications. 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.

Over the past five 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. The prostate HistoScanning (Advanced Medical Diagnostics ™) is a proprietary tissue characterization technology developed to differentiate, characterize and visualize prostate tissue, based on the analysis of backscattered ultrasound. Regardless of the published results, there are no analogue systems in use in Bulgaria and the authors aim to fill this gap. The most important distinctive features of the developed package are:

The input information is coming mostly from abdominal images, regularly used in mass screening in Bulgaria;

The system may be used also for TRUS images, which are more informative;

All processed images are available to physicians in a very simple and convenient environment. We rely on the physician knowledge and experience to fuse the most useful images and to summarize the results.

The capabilities of personal computers for parallel processing are used to create a plethora of processed/ filtered 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 [11] 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.

As a summary, it should be noted, that enhancements in ultrasound image processing would substantially raise the probability of early diagnosis of PCa, but it is only a small portion of the overall process of PCa detection and mortality reduction.

Algorithm Description

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, and the appearance of carcinoma on ultrasound is variable [6].

Since late 70s it is considered that the prostate is composed of three distinct glandular zones – transition zone, peripheral zone, and central zone. Later, it was reported by Lee et al [9], that the most common (70%-80%) of prostate cancers arise from the peripheral zone, on the contrary of transition zone, which is the site of the location of benign prostatic hyperplasia. The anatomic distinction between the central and peripheral zones generally cannot be

distinguished by ultra-sound. In a normal man, these two zones are seen as a homogenous, isoechoic area in the posterior section of the prostate. Their normal echo pattern is used as a reference for defining other structures as hypoechoic or hyperechoic [7]. The normal transition zone in a young man comprises only a small percentage of the gland and thus is difficult to image. In an older man with benign prostatic hyperplasia, the transition zone expands, compressing its surrounding fibromuscular band of tissue. This compressed tissue gives rise to the "surgical capsule" of the prostate, which is a sonographic landmark of zonal demarcation. The transition zone becomes moderately hypoechoic in comparison with the central and peripheral zones [8]. The highest predictive values for prostate cancer are seen in hypoechoic lesions that are well defined and are larger than 1 cm [10]. The etiology of this hypoechogenicity is currently believed to be due to the replacement of the prostatic stroma with infiltrating glandular elements. 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 [10].

Studies following Lee's work reported that a significant number of prostate carcinomas are isoechoic [9]. The average yield of a biopsy of a peripheral zone hypoechoic lesion has been 30%-50%. With these limitations, the image analysis should recognize more subtle findings such as irregularity or asymmetry, extension of hypoechoic areas from the central zone into the seminal vesicle, or any area corresponding to an abnormality on DRE. Finally, PCa usually characterizes with increased blood flow.

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. These features are embedded in the proposed in this paper software tool for PCa detection. The coincidence of the regions where they were detected indicates higher probability of PCa.

Like all imaging techniques, that use coherent energy, the ultrasound images suffer from multiplicative speckle noise, which is due to the coherent nature of the scattering phenomenon. This noise obstructs the image analysis and medical diagnosis. The methods for image quality improvement can be divided into two parts: the first one is at the stage of image formation and the second one is processing of the received (often noised) images from the first stage. There are many methods applied at the first stage, that significantly improve image quality like compounding, coded excitation and other but the speckle noise reduction often remains an indispensable image processing task. In the proposed program tool after selecting the region of interest (Region of Interest- ROI) four base steps of processing are implemented on the ROI image:

Filtering procedures. The most appropriate algorithms for noise reduction are smoothing filters. Several linear filters for image smoothing were included. For the linear filters the smoothing operation realizes as a local weighted average in the pixel's neighborhood, but it has poor edge-blurring effect. To avoid it several nonlinear filters are also implemented. The coefficient weights in these filters are especially chosen to preserve sharp edges simultaneously smoothing the surfaces. As a result, the nonlinear filters increase the contrast on the border of the objects, which is very important in the ultrasound image processing. Some of the available filters are: adaptive nonlinear Gaussian, anisotropic diffusion, combined stick filter, Kuwahara(1,2,3) and others. In our experiments, 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 included the fast Otsu algorithm and the LMQ (Lloyd-Max Quantizer) algorithm. The most important parameter of the segmentation algorithms is the number of thresholds. The bigger value of this parameter increases algorithm resolution (more features are segmented), but on the other hand, the big numbers hindered results interpretation. The selected number of thresholds should be less than 9, because the bigger number of thresholds leads to the approximation of the segmented image to the original image and the segmentation becomes meaningless. The other problem of the multilevel segmentation is the appropriate threshold choice. Usually the values of thresholds are defined adaptively according the pixel intensity statistics.

Texture analysis detects irregularities and anomalies in the prostate image on the base of the automatic description of a (или the) particular region. The so-called co-occurrence matrices are used [12]. 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 the Power Doppler images.

The output images are supposed to be more suitable for medical interpretation. The differentiated areas can direct the attention of the physician to some suspect tissues and help him for more informative decision making.

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 a multicore laptop with NVIDIA GPU supporting CUDA. The architecture of the system is displayed on *figure 1* and the experimental set includes a LOGIQ C5 Premium sonographic device, a TCP/IP network switch, a multicore laptop.

The program package is realized on MATLAB R2011a, using Parallel Computing Toolbox. This toolbox supports
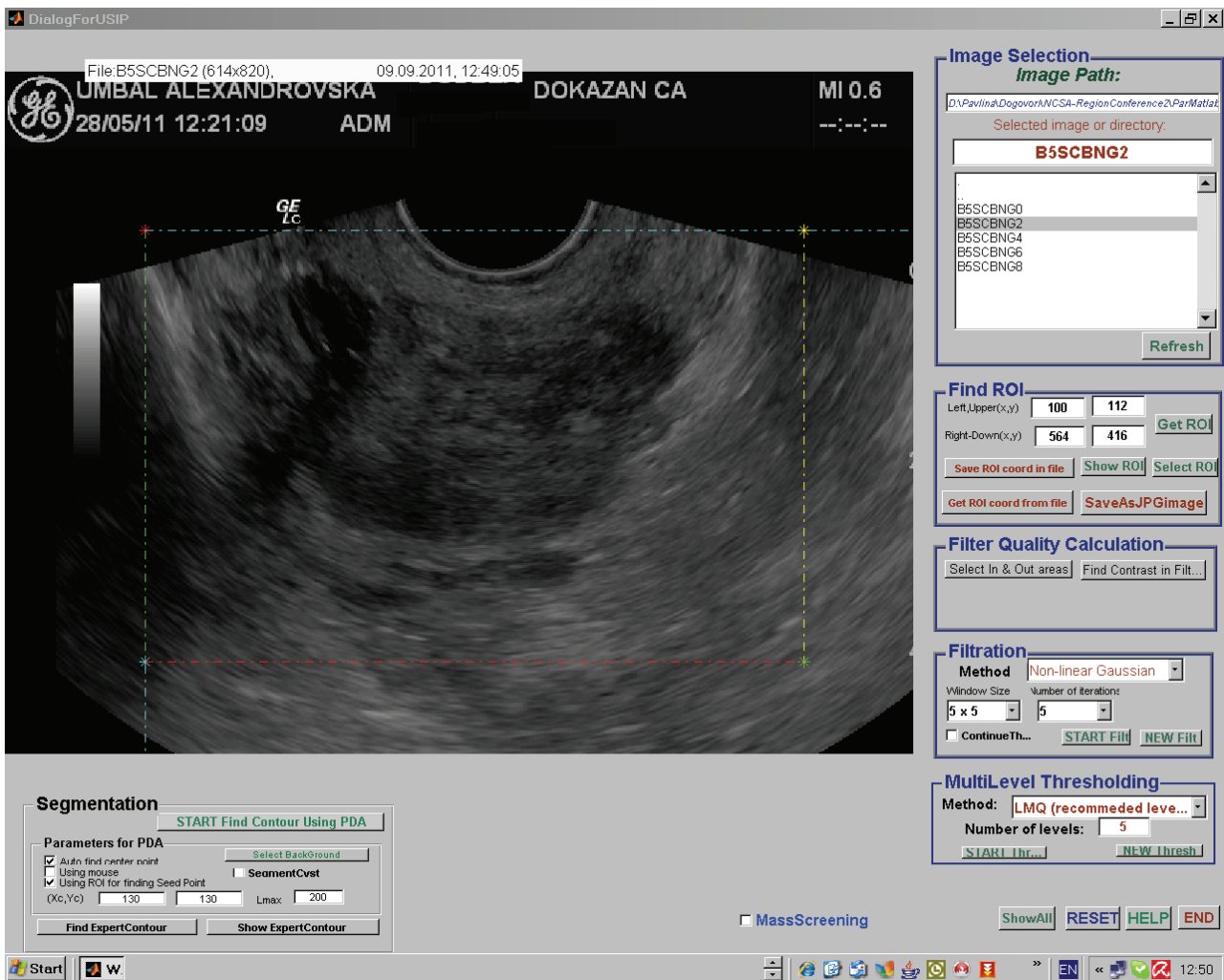
Figure 1. System architecture

Figure 2. Dialog window of the program interface with selected ROI
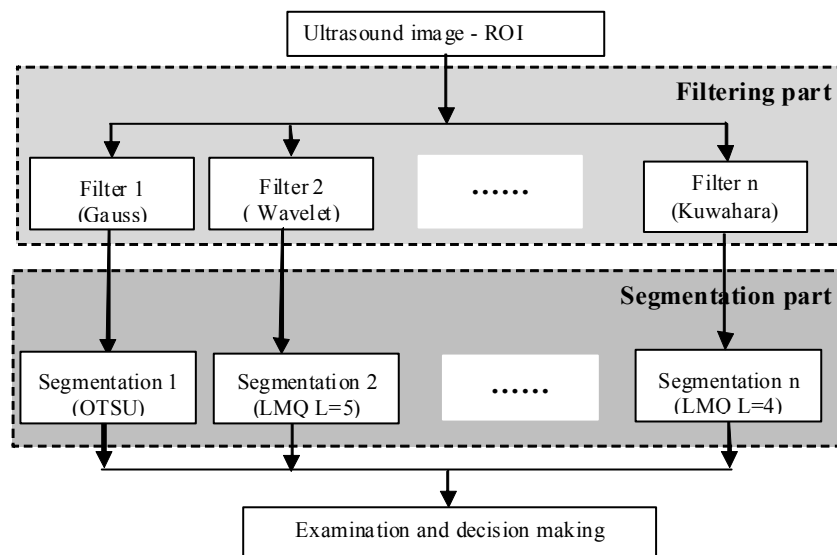
Figure 3. Block-diagram of the parallel algorithm

solving computationally and data-intensive problems using multicore processors, GPUs, and computer clusters. High-level constructs – parallel for-loops, special array types, and parallelized numerical algorithms allow programming of parallel applications without MPI programming. The toolbox provides eight workers (MATLAB computational engines) to execute applications locally on a multicore laptop. Without changing the code, the same application may be run on a computer cluster or a grid computing service (using MATLAB® Distributed Computing Server™). The parallel applications can be run interactively or in a batch. The developed program works in two modes. The first one provides a convenient interface for algorithms parameter tuning and output image selection. The graphical user interface consists of several panels with pop-up menus for selecting desirable methods for filtering and segmentation and input image selection by browsing through the directory tree. By default, the filter parameters are set to the optimal values depending on the previous experience. On *figure 2* an illustration of the program interface is shown. The selected image (received from UMBAL practice) visualizes prostate with proved cancer (after operation test). From ethical consideration the personal information is erased. The 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.

The second mode of the program has been developed for the case of mass screening. In this mode the interface for parameter settings is not available. The physician operates with medical ultrasound system and takes images from the observed prostate. When he decides to activate additional image processing he simply presses a programmed button and the selected image is automatically sent to the processing laptop via standard TCP/IP connection. The processing program activates automatically by new file

detection. The image is processed on several processor cores to speed up the calculations and to produce several output images in near real time. The mass screening processing includes only specified in advance filtering, segmentation and texture analysis procedures. The output images provide additional information to the doctor for reassured decision making. The doctor may save the images for further examination.

Parallel Realization

The filtering, segmentation and texture processing are time consuming. To speed up the calculations a parallel version is developed. The program block-diagram is presented on *figure 3*, where the number of parallel tasks is denoted by n.

Each task consists of two steps – filtration and segmentation. The tasks are differentiated by the used methods and design parameters. The results are visualized simultaneously on the screen for comparatively examination and decision making.

The used functions from MATLAB parallel toolbox are as follows:

By function findResource an object is creating in the local MATLAB session representing the local scheduler. Then, the statement createJob creates a job in the scheduler's data location. The createTask function creates the specified task in this job by pointing out the specified procedure to be implemented in parallel and the corresponding input data. This is parallelism of type spmd (single program code, multiple data). Then get(job1,'Tasks') is used to see the Tasks property of job1. By the statement submit(job1) the job1 is submitted (queued) for running. The function waitForState waits for the end of the job and after that the function getAllOutputArguments gets the

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

Figure 4. Code for MATLAB parallel processing

results. The parallel source code is presented on *figure 4*.

Results of Parallel MATLAB Implementation on PC

The results are shown on *figure 5*. *Figure 5a* presents the original ROI image. *Figures 5b, 5c* and *5d* present the corresponding results of several combinations of filtering and segmentation algorithms. On the figure the number of iterations is denoted by N, the window size by nw, and the

number of levels by L. The wavelet C2D abbreviation means complex dual tree wavelet filter.

Conclusion

A program tool for ultrasound image processing is proposed for computer aided medical diagnosis. Parallel implementation using MATLAB Parallel computing toolbox is realized. The parallelization speeds up the time consuming filtering and segmentation process and thus makes it
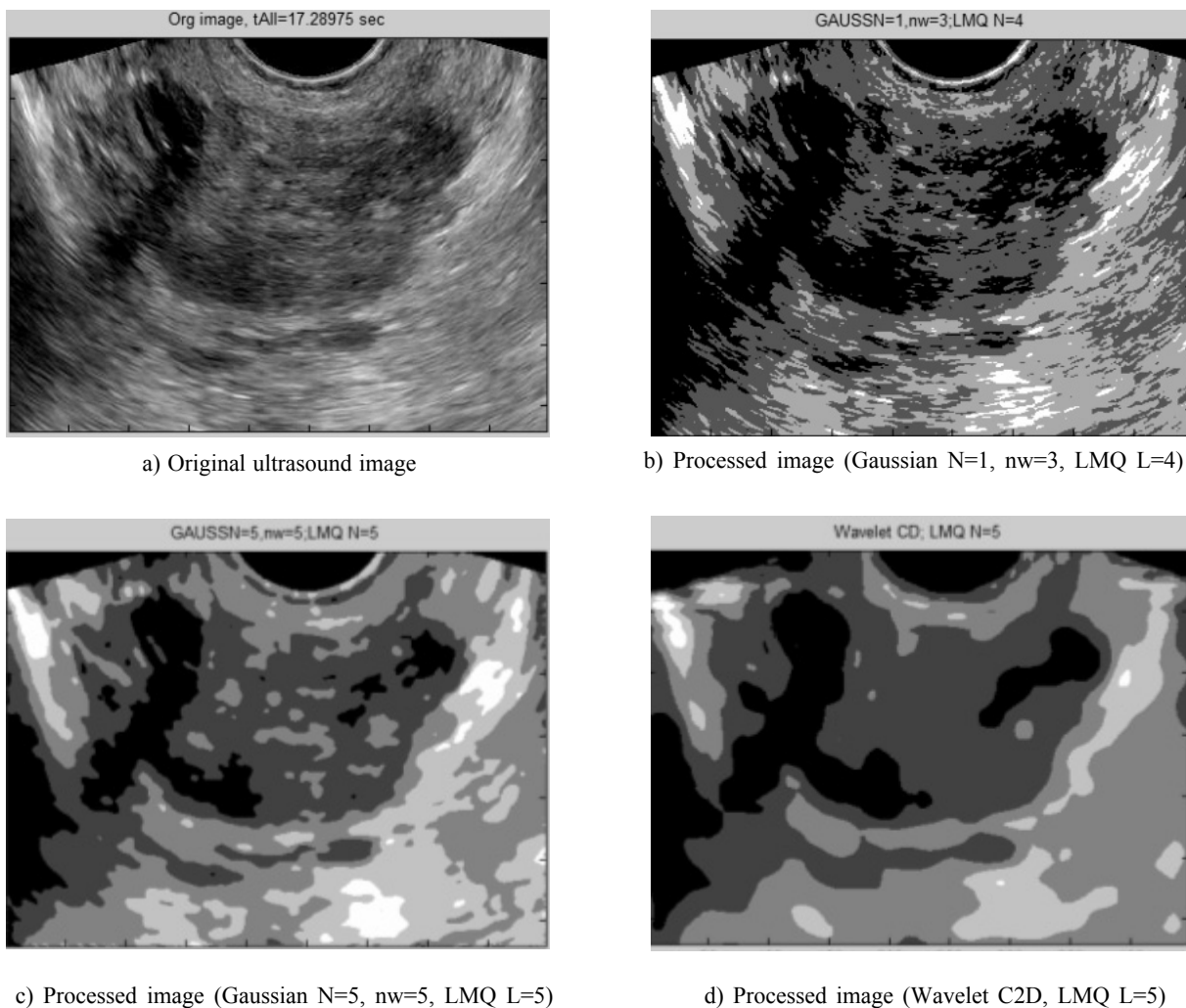

a) Original ultrasound image

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)

Figure 5. Results from the proposed software tool

possible for mass screening. Although the ultrasound examination does not guarantee 100% carcinoma detection, the proposed tool will support early PCa detection in mass screening. By visual reassurance for treatment decision-making process a reduction in mortality due to prostate cancer will be achieved.

Acknowledgments

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