Super-Resolution on Depth-Map Images

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Abstract—**Breast Cancer Conservative Treatment (BCCT) is nowadays the standard procedure to treat breast tumours. Initial assessment of the aesthetical outcome was performed by visual inspection and has many limitations. The Breast Cancer Conservative Treatment.cosmetic results (BCCT.core) software presents an objective evaluation of the cosmetic result, using frontal images of the patient. This system can be improved by the incorporation of tri-dimensional (3D) data, ideally acquired through a low-cost solution. A Kinect™ device can render a depth-map of a scene with relative low resolution. Resolution enhancement through Super-Resolution (SR) techniques is necessary before further processing. This paper presents a brief comparative study of state-of-the-art Super-Resolution algorithms performance applied on the captured Depth images from the Kinect™.**

Keywords: Super-Resolution; Depth-map images; Breast Cancer Conservative Treatment; BCCT.core; Kinect.

I. Introduction

Breast Cancer is the most common tumour affecting women, presenting a ruling impact on women physical image. Nowadays, the standard procedure to treat breast tumours is the BCCT. It provides better aesthetical outcomes, and women are expected to cope with the treatment consequences for an extended period of time. The assessment of the cosmetic result is usually performed by one or more observers and, inheritably, decisions are subjective and present disparities when comparing different assessments. Therefore, the inexistence of general measurements for the cosmetic outcome leads to the necessity of replacing the subjective evaluation with an objective and reproducible method.

BCCT.core is a software system that provides an objective aesthetical evaluation of the cosmetic result. The current system uses frontal digital images from patients, but has proved capable of being improved with the inclusion of 3D data [1]. The aim with this project is to contribute with enrichment of the data collected from a Kinect™ device before further processing. Therefore, resolution enhancement of the low-resolution depth maps captured is necessary, to which SR methods will be employed. With the inclusion of two-dimensional (2D)+3D information, we expect to improve the performance of the current evaluation system.

II. BCCT.core System

BCCT.core is a semi-automated software system to obtain a valuable objective and reproducible assessment of the aesthetic result for the BCCT [2]. It is able to extract features such as: breast asymmetry, skin colour and scar visibility from frontal images of patients. Furthermore, it is capable of detecting breast contours and to automatically extract features related to the aesthetical outcome. It is also possible to use this system as a mean to improve current treatment techniques and to compare assessments of different work teams. The system is already being used in several institutions. Although, recovered feedback show the necessity of improvements.

A. BCCT.core Using 3D Data

For the inclusion of more information about the breast shape, Oliveira et al. [1] conducted a study and development of low-cost and ease of operation solutions to gather a 3D model of a female torso. The use of a Kinect™ device to acquire depth-maps of a scene allowed to detect volumetric differences, and produced satisfactory results. This device comprises the requirements of being both low-cost and user-friendly. With the gathered 3D data is possible to produce models that can be viewed from different angles and produce more measurements based on that data that is inaccessible from patient's photographs. This would bring BCCT.core valuable measurements to complement its overall aesthetical assessment of breast interventions outcome. Still, this acquisition system may pose difficulties due to its own limitations. The disparity maps obtained have relatively low-resolution, which may obstruct the construction of a reliable model. Therefore, the enhancement of the captured images can be essential before their use in later steps.

III. Super-Resolution

Super-Resolution is the process which employs techniques to enhance the resolution of a single or a set of images [3, 4]. Authors usually refer to SR as a 3-step process: (1) image registration; (2) image interpolation and (3) image regularization. Each step is covered in the literature and many authors have performed diverse methodologies to apply SR. Image restoration is typically an ill-posed inverse problem and is generally modelled as in (1) [5]:

$$y = DHx + v \tag{1}$$

Where y is the low resolution image and x is the unknown high resolution image. D and H are degrading operators regarding the downgrading blur and noise present in the image, and v is addictive noise. SR aims to recover missing high-resolution details that are not explicitly found in individual low-resolution images. One of the downfalls of resolution enhancement is the smoothness created in some zones which translates into a loss of detail. The opposite can also occur, especially in small high frequencies zones like edges, representing a poor reconstruction.

The nature of the captured low-resolution images, in gray scale, and the necessity to maintain the quality of edges, smooth areas and gradient consistency, make good qualities that any SR methods must render. These features must be preserved properly with minimal degradation not to incur into model deviations to the actual physical form of the breast shape.

IV. Results

Preliminary tests were conducted in order to understand the performance achieved by SR methods. In total, eleven programs were tested, ten of which were Matlab® implementations and one being a binary executable written in C/C++. Some did not fully comprehend the extension of all SR steps and focused on a single step. Out of the eleven, only six were deemed to execute or produced viable results. Programs were named accordingly to the order they were tested, assuming a nomenclature of "*program#<number>*". Experiments were conducted with a total of 144 images, comprising 47 patients. A synthetic, gradient-like, image was also put under scrutiny of the tested methods. Due to its linearity, any method should cope far better with it then any other type of image. This was used to confirm the applicability and results of the methods. All methods were tested for a scale factor of 2 and, accordingly to their nature, either using single or multi-image based approaches. Images were acquired through the

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Kinect™ and downsized, with the same scale factor of 2, and then subjected to SR methods so the final spatial resolution matches the original. For comparison purposes the original images were the ground truth against the resulting enhanced images.

A. Experimental Results

The results for the application of SR methods are summarized on TABLE I. It is shown the average Peak Signal to Noise Ratio (PSNR) value obtained for each program, and its medium execution time to produce a single image. Clearly *program#10* [5] shows the best results for obtained PSNR which was matched by visual inspection, presenting itself as the best option. Not to exclude other programs which also provided acceptable results, as depicted in Figure 1, the choice fell on *program#10*. This was due for the necessity of the best possible reconstruction of the high resolution image, and its consistency on the performance.

Tests with the synthetic image have showed the expected better achievable performance, although with some interesting results. Programs *#1* and *#8* showed the same result: 50.94 decibels (dB) which did not differentiate any of them in the course of the tests. *Program#4* seems to be unable to deal with such a linear image and produced an almost black image (registering 5.05 dB). *Program#5* recorded a better result than *#1* and *#8* with a PSNR value of 55.05 dB, representing a good increase in performance. The best registered increase was with *program#10*, which recorded a 70.40 dB PSNR value. Again, it outperformed other methods both in PSNR value, performance increase and visual inspection.

For all the experimental procedures, Matlab® R2011a development environment was used, running on an Intel® i5 M450 (@ 2.40 GHz) with 4 GB of RAM machine.

V. Conclusion

In this paper we present a study on the performance of several SR techniques applying them to our project's type of images. It is possible to detect the potential of the use of SR methods to enhance images resolution, before proceeding to further processing. Three programs recorded an average PSNR value above 45 dB, one of which even recorded an average above 50 dB. This presents a good reconstruction as confirmed by visual inspection and a starting point for the next steps.

Further works shall concentrate on the study of applicability of the enhanced images, much to their use on the definition of new 3D features. Its results should be study in order to improve BCCT.core evaluation system overall.

TABLE I. Experimental Results

Program	**Average Results**		**Standard Deviation (dB)**
	Execution time (seconds)	***PSNR (dB)***	
Program#1	1.66	46.0	0.8
http://lcav.epfl.ch/software/superresolution			
Program#4	65.30	13.0	9.6
http://www1.idc.ac.il/toky/videoproc-07/projects/superres/srproject.html			
Program#5	444.42	40.1	1.3
http://www.ifp.illinois.edu/~jyang29/codes/ScSR.rar			
Program#8	3.00	46.0	0.8
http://rr.epfl.ch/3/2/VandewalleSV06_matlab.zip			
Program#10	380.99	51.4	1.2
http://www.comp.polyu.edu.hk/~cslzhang/ASDS_AReg.htm			
Program#11	7.35	40.1	1.0
http://www.comp.polyu.edu.hk/~cslzhang/code/NL_Back_projection.zip			

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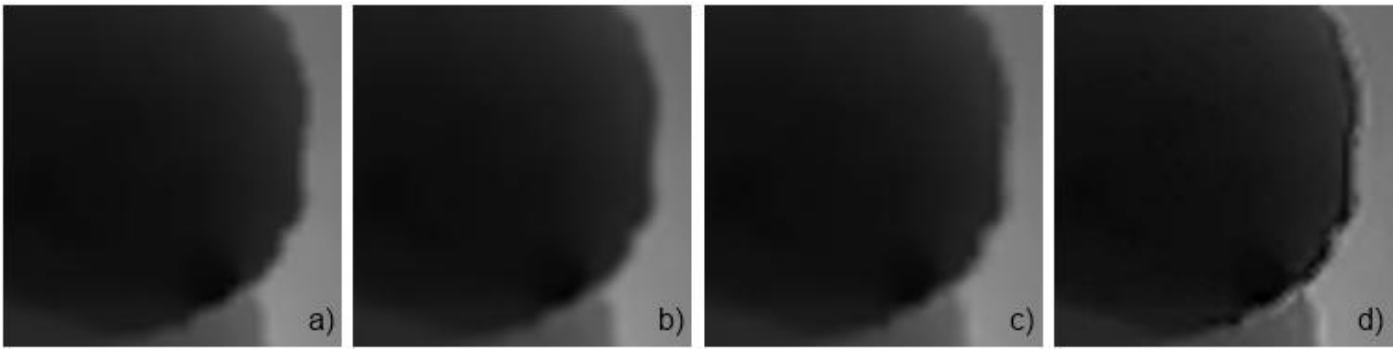

Figure 1. Region of Interest in a standard image from patient (zoomed). ((a) Ground truth; b) Program#10 output image; c) Program#1 output image; d) Program#11 output image.) NOTE: Image quality may not be the best in printed versions.