DIGITAL CAMERAS AS LOW-COST TOOLS FOR TELEMEDICINE AND E-HEALTH
Opportunities and Constraints

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Abstract: The aim of this paper is to present part of a research work oriented to selection and usage of low-cost imaging devices for Telemedicine and e-Health. The results presented are oriented to increase the usability of digital photo cameras as a device for creating and/or digitalizing medical images. All activities are part of a DAPSEpro project "Medical data acquisition, processing and collection for e-Health solutions".

1 INTRODUCTION

The aim of this paper is to present current results of the DAPSEpro project "Medical data acquisition, processing and collection for e-Health solutions" in the part oriented to selection and usage of low-cost imaging devices and following image processing for the needs of telemedicine and e-Health. The present work is the result of the partnership between the Technical University of Sofia and the Medical University Sofia (clinics of nephrology and pulmonology).

2 MOTIVATION

Under the DAPSEpro project one of the initial tasks was in the field of "digital libraries" and especially - the need for digitalization and archiving of patients' old X-rays. This provoked the development team to design and implement a technology to solve this problem.

Basic requirements and limitations for the fulfilment of this task were:

- the ability to obtain 'acceptable' images from all size classical X-ray pictures such as old X-rays, badly preserved X-rays, or ones made on a poorly calibrated older generation machines
- very limited financial resources for new equipment
- a quick and inexpensive image digitalization process (Marketing research envisaged similar services in prices between 5-15 USD depending on the size and quality due).

Two possible solutions were investigated:

- usage of existing scanners for X-ray pictures or scanners for semitransparent images
- design of specialized low cost system for X-rays images digitalization.

To use existing scanners was impossible for the following reasons:

- scanners, which can be used for all sizes of X-rays at the required quality and speed, are too expensive
- reasonably priced scanners have a number of disadvantages:
  - the scanning process is very-to-extremely slow
  - any high quality scan needs unacceptably long processing time

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  - pre-view and real scan are two different phases and both are of long duration
- if the picture is bigger than 420x297 mm (format A3) in any dimension the following problems appeared:
  - The picture has to be scanned in sections. This requires adjustment of the picture section by section to the axes of the scanner for the needs of the stitching process. In practice this is not absolutely possible or is very time-consuming, requires skills and experience. In this case stitching is mandatory. Because the scan process is not automated stitching cannot be automated either.
  - In case when the top optical plane of the scanner is under the top end of the scanner case processing images bigger than A3 is impossible because they have to be bent to follow the top surface shape.
- only few scanners include a light intensity control function
- a selected target zone of the picture cannot be zoomed optically.

These observations directed our efforts to design and implement a specialized scanning machine. The first implementation used as a basis for new research was a successful project implemented 10 year ago, and it is still in operation in the Institute of Orthopedics of the Medical University Sofia - a system for handling X-ray images. Under this project, together with colleagues from Sofia University a system (a scanning device and software for image processing) was designed and developed. It is based on a digital video camera with high optical zoom (20x) and black and white sensor with an 800000 real pixels matrix. The success of this solution proved the feasibility of low-cost solutions based on modern digital photo- and video cameras.

The exploitation of the system revealed some limitations, which were both the result of the quality of the video cameras from that period, and the peculiarities of the use by physicians:

Influence of the parameters of the optical system and sensor matrix on the usability of the system, differences in the perception of a digitalized X-ray image and a classical X-ray film from medical point of view; the limitations of the human eye and related problems to achieve realism. These observations accelerated our work significantly.

3 THE LIMITATIONS OF THE HUMAN EYE: HOW TO ACHIEVE REALISM IN THE DIGITALIZATION PROCESS

A major problem in using computers for image visualization is the characteristics of the human vision as a system for perceiving visual information: in many aspects the human eye is an extremely sensitive sensor, while for other things it is a very imprecise one. This requires the use of special computer visualization techniques targeted to the application area: while with special effects for the cinema the aim is to "trick" the eye while in scientific visualization the goal is to increase the perception and understanding of information.

One of the specifics of digital images as a basic information source is that they have to be visualized on many different types of output devices or media. In present medical applications usually these are different types of monitors and less often reproduction on paper or film.

The sequence “image digitalization – image visualization” generates new problems. Some of them are:

- The terms “color space” and “color model”: the color space represents the set of possible colors to reproduce; the color model represents a method of presentation of colors by a group of primary colors. The color space of the human eye (known as CIE 1931 x,y chromaticity space – see Figure 1) is much greater than that of any input and output digital device. In addition, the color space of the digital photo and video cameras (known as Adobe RGB) is also greater than that of computer monitors (known as sRGB). Additional sources of errors are imprecisely (and/or wrongly) calibrated devices (white point temperature characteristic). The white point is the point of the color space and its incorrect value moves along the line in the chart, i.e. moves the device color space within the human eye perception area. This changes the perception of purity and color saturation which is inadmissible when the color is the main source of information in the image.
- One of the main problems in the image perception is the perception of 'visual weight'. This allows the perception of some parts and the suppression of others, according to their location in the image and the surrounding areas. For medical

imaging this is particularly important because black and white images are widespread: X-rays, ultrasound and similar. An example is shown in Figure 2 – scanned X-ray image and its negative.

- The human eye has an exponential law of perception change depending on light intensity, i.e. the sense of change for a color close to black and another close to white is associated with a very big difference in the change of intensity for both colors. This could seriously change the perception of B/W images particularly on the LCD-monitors, such as laptops, as a function of the slope of the monitor. For example, when one needs to observe white details against a black background (figure 2a) the optimal position is close to the perpendicular to the view direction, while the opposite case (figure 2b) requires a noticeably greater slope.

- The property of human vision, called "Approximate color consistency", is another source of very serious difference between classical examination and the use of digital images. In nature, when a human perceives two light sources as equally white and they illuminate both sides of one and the same object, the perception is the same color of the two object sides. Shooting the same object by digital camera has a different result: the color of the object depends on the temperature of the light source. The property of human vision, called "Approximate color consistency", is another source of very serious differences between direct observation and the use of a digital image. In medical applications this problem can be seen best in the imaging and visualization of human skin.

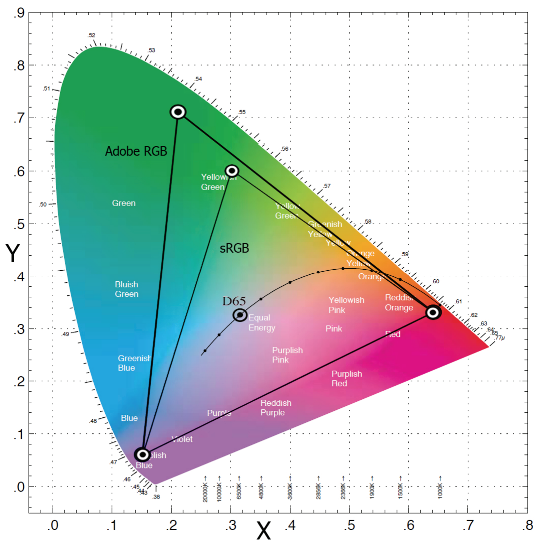

Figure 1: CIE color space.

4 CAPABILITIES AND LIMITATIONS OF DIGITAL PHOTO CAMERAS

Modern digital photo cameras have a very high potential, but the selection of an appropriate apparatus is not a trivial task. It is necessary to examine several key features and their mutual influence on the shooting process. It is not rare that individual characteristics of a good, but not user-friendly digital camera require professional photographic skills. It should be noted that the basic requirements according to target area - color images obtained for imaging (e.g. for the purposes of dermatological remote diagnostic activities) or digitalization of existing images are different.

When using color images there are two essential characteristics: white balance and camera color distortion. White balance directly affects the color change because the temperature of the light source affects the location of the 'white point' on the "Equal Energy Curve" in color space. An incorrect setting can result in the following side effects: decolouring, bluish-green or reddish areas or spots. These effects increase when shooting human skin because of natural phenomena known as 'subsurface scattering' and 'caustics'.

Color distortion is a feature of the cameras, showing how natural color is perceived by the camera when lighting is correct, i.e. shows a replacement of natural color with a color from the camera color space:

- digital cameras have completely different characteristics, resulting from the combination of lenses and an optic system, a sensor matrix and embedded digital algorithms
- there are no cameras with equal color distortion for different shooting modes for both single shooting and video
- the setting for the film sensitivity (ISO value) also affects the color distortion.

When the apparatus is used as a scanner the key characteristics are: optical distortion (barrel or pincushion); gray scale accuracy; sharpness, low contrast details and resolution; embedded noise reduction algorithms.

- The availability of optical distortion above 1% is a limitation in the following cases:
  - the use of images for measurement of lengths, angles, distances, curves;

  - very big X-ray pictures and/or need to increase the depth of the digital image requires scanning in parts: in this case optical distortion prevents the final stitch procedure;
  - if a low level of distortion results from digital processing by camera firmware no more than 2/3 of the image can be suitable for measurement or stitch procedures.

- Digital cameras use a 3-channel (R, G, B) sensor matrix. For B/W images these devices use digital algorithms converting R-, G- and B-values for each pixel in the intensity (gray colors): the type and quality of the embedded algorithms specify the correctness of the gray palette. In different shooting modes and under different conditions, the gray palette accuracy varies because the sensitivity of the matrix color channels is changed differently.
- Digital cameras with excellent algorithms for noise removal are suitable for laymen but from a technical point of view their algorithms may distort the realism of shooting images: some algorithms are too aggressive, and as a result, small size details disappear from the image.
- Sharpness, low contrast details and resolution determine the level of detail that can be achieved in different shooting conditions.

As a result of investigation and analysis of many digital cameras and experiments with a number of led to resulted to the following set of requirements:

- the camera should have a manual mode:
  - After a stitch procedure the scanned image will have the necessary quality and reliability only if all parts are shot in the same mode and camera settings.
  - If color images are used to trace the growth of some processes, the accuracy of the analysis and results is determined by the camera settings for each photo: different settings generate different color distortion. As a result, one and the same color in two images will result from two different natural colors.
- the camera must ensure an adequate optical zoom:
  - scanning activities require minimum 10x optical zoom, but the optimum is 12x or 14x based on sensor matrix size
  - if color images are used to trace the growth of some processes the required optical zoom is determined by the camera: one has to compare the quality of images taken at close range with no zoom, and those taken form a greater distance and zoomed.
- Cameras with less than 7 million effective pixels are useless. The scanning process requires 10 to 12 million effective pixels. Current cameras with more than 14 million pixels are too noisy.
- Preferable cameras are those with least optical distortion and chromatic aberration ("aberration" means that some artefacts are added to the image).
- Cameras with weight less than 300 g require much cheaper carrier mechanics for some activities.

A significant advantage is the ability to control and manage the camera firmware externally. This provides much greater flexibility and expands the usability of the apparatus for the purposes of Telemedicine and e-Health.

5 IMPLEMENTATION RESULTS

Two classes of digital photo cameras are used for the development of camera-based scanning devices: "Compact Super Zoom" (manual mode, 12x optical zoom, 12 M effective pixels, less than 1% optical distortion, <300 g) and „Compact" (manual mode, 4x optical zoom, 7 M effective pixels, ~ 1% optical distortion, ~ 220 g). Cameras of the "Compact Super Zoom" class have provided much greater opportunities for developing devices which will substantially expand the potential applications of the system. All results described below are based on the use of devices with this type of camera.

When using a digital camera as 'camera' (creating images from nature) some new possibilities are discovered:

- It is possible to create a model of image transformation which allows the use of different shooting settings when color images are used to trace a growth. So far experiments have been conducted only with the basic camera, but future plans are to extend them to other digital photo cameras.
- A method for using the captured image as a basis to create a pseudo-3D image was developed. This may improve the diagnostic possibilities when additional information for texture is needed.
- The ability to manage firmware extremely enhances the use of the digital photo camera. An example is the possibility for direct capturing of static and dynamic stereoscopic images. This will allow remote obtaining of real three-dimensional images.

The results of using cameras as a scanner device demonstrate the usefulness of this approach and also that scanning with a resolution below grain size of X-ray film is no longer a problem. This increases the useful information, allowing digital processing to eliminate errors in the final images (figures 3 and 4).

For X-rays having one of the following defects (see figure 5) the developed technology significantly increases perception (figure 6):

- X-ray images with overexposure
- X-ray images with underexposure
- Incorrectly treasured up X-ray images
- A badly calibrated X-ray machine: overexposure and underexposure areas in one and the same image.

6 CONCLUSIONS

The images prepared and used for the present paper were the ones used for diagnostic purposes and served to confirm diagnoses made by other means. Additionally it was confirmed that personnel with lower qualification can easily interpret images. Finally it was confirmed that images with very low quality can be processed and interpreted. This demonstrates the great potential of digital photo cameras for Telemedicine and e-Health applications.

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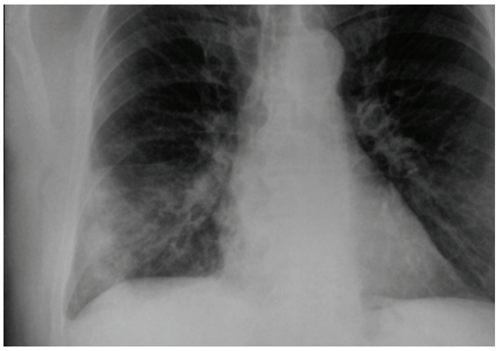
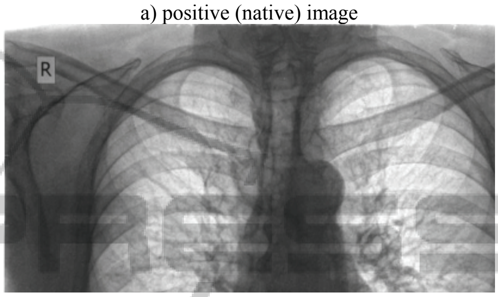
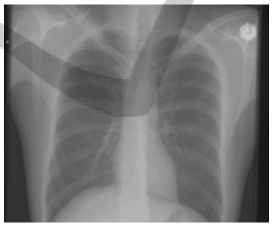


a) positive (native) image

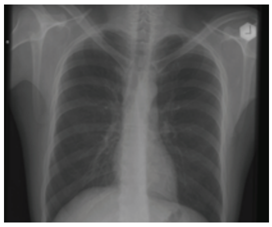


b) negative image

Figure 2: The "visual weight" can substantially change the perception of details.



a)



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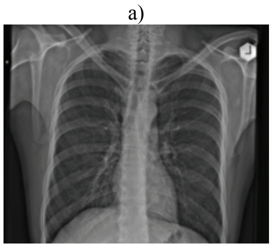
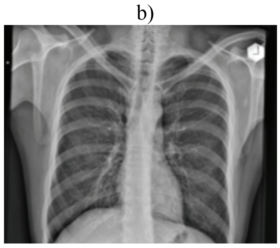


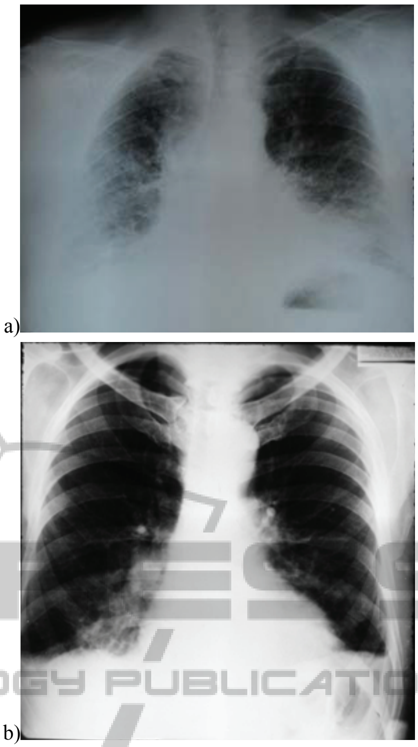
c)



d)

Figure 3: Some examples of image quality of scanned by digital photo camera X-ray image.

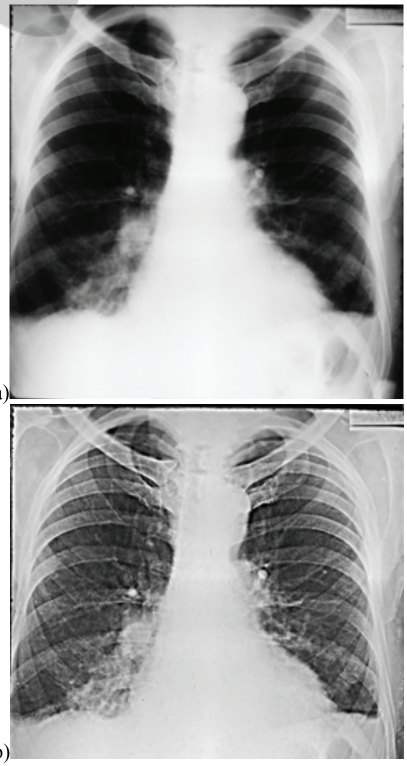
Figure 4: Different levels of details for scanned with digital photo camera X-rays.



a)

b)

Figure 5: a) X-ray image with overexposure. b) Badly calibrated X-ray machine.



a)

b)

Figure 6: a) Scanned X-ray image. b) details that can be obtained after processing.