Strategies for Wound Image Understanding

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Abstract — **This paper presents a Java framework for analyzing, processing and understanding wound images, to be used in teaching, learning and research activities. We intend to promote e-learning technologies in medical, pharmaceutical and health care domains. Using Java and XML technologies, we build models for various categories of wounds, due to various etiologies. Based on color and texture analysis, we identify the main barriers to wound healing, such as tissue non-viable, infection, inflammation, moisture imbalance, or edge non-advancing. This framework provides the infrastructure for preparing e-learning scenarios based on practice and real world experiences. We make experiments for wound healing simulation using various treatments and compare the results with experimental observations. Our experiments are supported by XML based databases containing knowledge extracted from previous wound healing experiences and from medical experts' knowledge. Also, we rely on new paradigms of the Artificial Intelligence for creating e-learning scenarios to be used in a context of active learning, for wound image understanding. To implement the e-learning tools, we use Java technologies for dynamic processes and XML technologies for dynamic content. Our approach to e-learning is so called blended learning, which combines traditional face-to-face and Web-based on-line learning, with focus on principles of active learning.**

I. INTRODUCTION

Medical images are valuable in didactic activities for students in medicine and pharmacy. Digital pictures are in great demand, because digital technologies provide unlimited resources for medical and pharmaceutical education. Computerized image processing contains methods for non-invasive wound evaluation, allowing an accurate diagnosis in a large category of patients with damaged and wounded skin. Traditional non-invasive technologies are limited frequently to subjective visual evaluations. Color and texture information provide the infrastructure for a structured approach to non-invasive wound assessment. We use the RGB (Red-Green-Blue) color space to define a set of image features for every category of wounds. To identify a wound in an image, we implement specific methods based on some generic criteria, such as normal skin and wounded skin. For some applications we use as main colors Red, Yellow and Black to assess the gravity of a wound. Generally, wounds have a non-uniform mixture of yellow slough, red granulation tissue and black necrotic tissue. Relying on a high quality of image acquisition, we can analyze a succession in time of more images for the same wound and assess changes in wound healing, i.e. the recovery or worse evolution.

We intend to develop e-learning tools for students and residents in medicine, pharmacy and health care, to be used in both didactic and research activities. In a previous work, we defined and implemented in Java an intelligent and practical educational environment, useful for designing and implementing e-learning scenarios. The first applications we developed and implemented for this educational environment were some e-learning scenarios for biostatistics. We will extend this system with specific e-learning scenarios for medical education. Our aim is to create and implement in Java an automatic method which can be used as a reference standard for color and texture wound analysis. The purpose is to create e-learning scenarios for wound image understanding and wound healing simulation, by applying this method to large amounts of wound image data stored in XML based knowledge bases (see Fig. 1). Our objective is to develop appropriate skills in wound management for a learner that traverses such an e-learning scenario. The e-learning scenarios are practice driven and relevant to professional practice, being used by students in medicine and pharmacy, at graduate, postgraduate and residency levels.

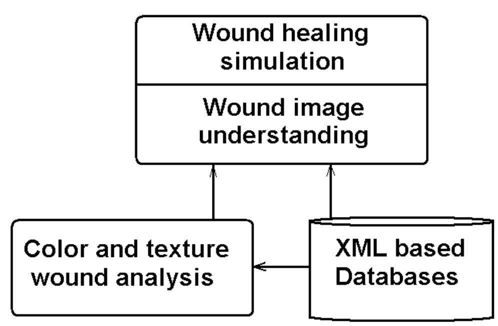

Figure 1. The general method applied for wound image understanding and wound healing simulation

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Wound image understanding is a difficult knowledge-based process and we have to use the new paradigms of the Artificial Intelligence (e.g. Bayesian Inference, Case Based Reasoning and Intelligent Agents) to manage it. Relying on large amounts of wound image data collected from medical and health care environments, we intend to create XML and CBR (Case Based Reasoning) knowledge bases, working in a continuous collaboration with physicians and wound care experts from our university and from health care and medical units. We have continuous access to actual medical records, to monitor the wound evolution and to verify both the accuracy and the consistency of our system. The advantage of using Java for this purpose is the integration without any difficulty with other Web based facilities.

Our approach to e-learning is so called *blended learning*, which combines traditional face-to-face and Web-based on-line learning, with focus on principles of *active learning*. The originality of our work consists in relying on new paradigms of artificial intelligence for creating intelligent and practical e-learning tools to be used in a context of blended and active learning. To implement these e-learning tools, we use Java technologies for dynamic processes and XML technologies for dynamic content. We create XML based databases containing knowledge extracted from previous wound healing experiences and from medical experts' knowledge. The methods presented in this paper should be useful as an adjunct to traditional teaching and learning resources. In a context of blended learning, the teachers and learners may combine the color and texture based parameters with traditional parameters, such as smell, venous and arterial status, patient history, etc.

II. IMAGE PROCESSING

The infrastructure of our system is based on a collection of Java class libraries, containing methods for processing images specific to various categories of wounds [7]. We implemented general methods that create many common special effects and use them in analyzing the wounds.

A digital image consists of a two dimensional array of pixels P_{mn} with m rows and n columns. Using Java language, this image is represented in internal memory as a three dimensional array P_{mn4}, each pixel being described in a specific RGB format by four unsigned 8-bit integers [8]. The first three integers represent the base color components (Red, Green and Blue), and the fourth integer, referred to as α (alpha) represents the transparency. A specific color is obtained by mixing different amounts of basic colors (red, green and blue) with a specific transparency. The standard Core Java Technologies provides methods for processing digital images, such as blur, sharpen, brighten or tone down an image. We will create the Java framework by implementing the image processing algorithms into one of the following two layers:

- Layer 1 – for low-level implementations, allowing to operate directly on pixels.
- Layer 2 – for high-level implementations, based on standard Java libraries such as JAI (Java Advanced Imaging) API.

For a given wound, we must find out some quantitative and qualitative attributes for assessing the healing state. As quantitative attributes we measure its surface area and its volume (evaluating depth). The original image is processed with the purpose to emphasize the distinction between wound and non-wound area. We use some general methods to enhance the image, because we must exaggerate the distinction between wound and non-wound. As an example, for individuals with fair skin, we lighten the images and then view them using shades of green with the red and blue minimized. This way more clearly exhibit the borders of the wound than in the original image. Removal of the red and blue leaves the wound black and the rest of the image green. For images of individuals with dark skin, both the red and green are accentuated while the blue is minimized. This procedure also leaves the non-wound area green, but colors the wound red. In either case, the wound can easily be distinguished from the non-wound without difficulty. We implement e-tools that will enable to assess the current state of the wound and to gain insight into the wound evolution, by comparing the series of wound data collected over time. Based on this knowledge we can design an e-tool for simulating the process of wound healing. The color image processing is the most acceptable automatic method of objectively and reproducibly analyzing skin wounds and lesions.

III. IDENTIFYING THE WOUND

The first task we face with in our system is to identify the wound in a digital image. Indeed, before analyzing a wound image, it is necessary to identify it. For this purpose, we implemented specific methods based on some generic criteria, such as normal skin and wounded skin. As a general approach, to identify the wounds it is necessary to traverse two phases: a pre-process phase and an identification phase. In pre-process phase, the original image is transformed with the purpose to emphasize the distinction between wound and non-wound area. As specified in previous section, we use some general methods to enhance the image, because we must exaggerate the distinction between wound and non-wound. In the identification phase, the image is divided into little boxes, then start analyzing each box for color profile, determining the percentage of main colors. It is examined the difference in the color profile of each box to the color profile of a box covering healthy skin, taken from outside the wound area. The distribution obtained from a box with healthy skin can be used as a benchmark. Other distributions are then compared in statistical terms with this baseline distribution and decisions are made on determining the edge. Wound area and different color percentages follow from this as well. The degree of deviations from this benchmark distribution can then be used to classify wounds. Assuming normality, the first two moments (the mean and the standard deviation) estimated from a sample will determine the color and texture distributions. The edge identification has an element of subjectivity which is left to the medic or wound specialist to set. Say for example, that wound edge starts if the color profile changes 40%, 70% or 90%, depending on how sensitive we want the detector to be.

A. User Oriented Applications

We implement the process of wound identification in user oriented applications, endowed with friendly GUI (Graphical User Interface), to be used in didactic and research activities. When an application is launched, it makes the following general actions:

1. Reads the digital image in main memory.
2. Convert pixel data of the digital image into a three-dimensional array that is better suited for processing.
3. Make a working copy of the three-dimensional array, in order to avoid having to make changes to the original array of pixel data. The working copy is sacrificed in the process of analyzing and processing the image, while the original image rest unchanged.
4. Display on the same frame both the original image and the modified image that contains the output results.

Fig. 2 shows the output result displayed by such an application launched to identify a wound. The left hand side contains the original image, while the right hand side contains the clone image, processed and marked with the contour of the wound.

The process of identifying a wound is very complex and relies both on new paradigms of the Artificial Intelligence and on user's skills to set some input parameters. As an example, the user may follow a very simple procedure to interactively identify a wound:

1) Select a representative area for the wound.
2) Select a representative area for the normal skin.
3) Push a button to begin the analyzing process for identifying the wound.

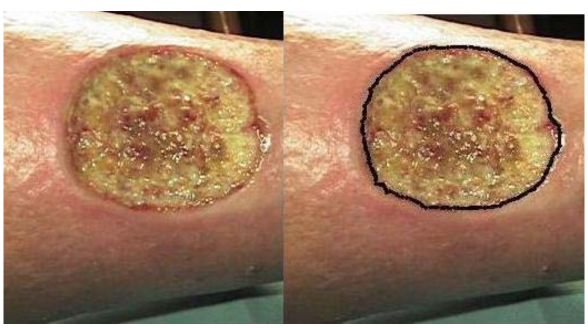

Figure 2. The output result of identifying a wound

B. Strategies for Wound Identification

Our system contains two general strategies for the process of identifying the wounds: a global strategy and a wound by wound strategy. The user may choose one of the two general strategies, or may combine them using a friendly graphical user interface. These strategies have the meanings presented below. Also, we implemented edge detection algorithms to be used in developing strategies for wound identification.

Global strategy **-** When apply the global strategy, the whole image is traversed from top-left corner towards bottom-right corner, applying specific methods for edge-detection and wound identification. The output result presents all the wounds identified inside the current image (see Fig. 3).

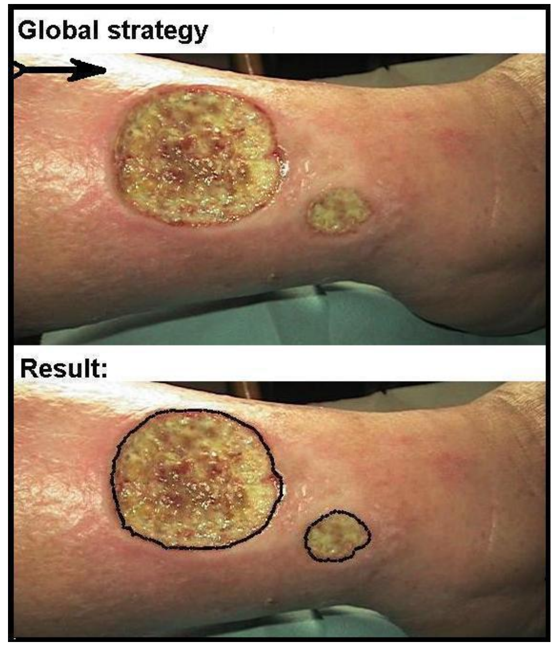

Figure 3. The result of global strategy

Wound by wound strategy **-** When apply the wound by wound strategy, each wound is identified in a separate process, based on a representative area belonging to it. In this case, only the selected wound is traversed, starting with representative area and going towards the four main points: top-left, top-right, bottom-left and bottom-right (see Fig. 4).

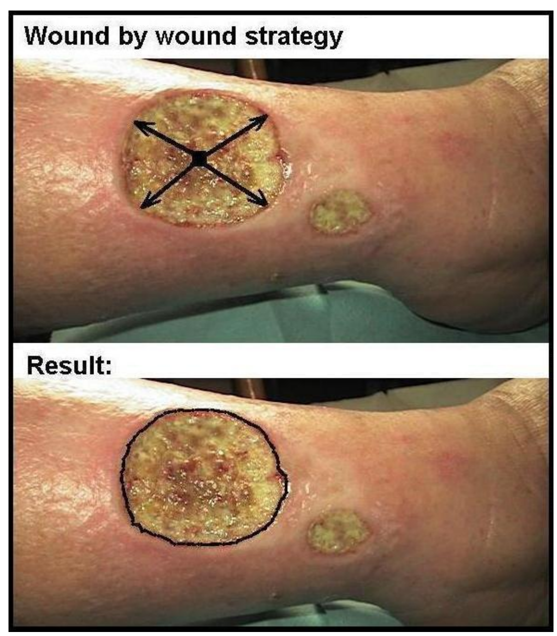

Figure 4. The result of wound by wound strategy

Edge Detection - The process of edge detection is very complex and difficult. We have to enhance the image, because we must emphasize, or exaggerate the distinction between wound and non-wound. For this purpose we use a convolution. Also, when we traverse the wound for edge detection, we have to look around, using Artificial Intelligence technologies. Sometimes we have to use details about distribution of the color values, such as Skewness and Kurtosis. We implemented the process of edge detection in two phases:

- *Phase 1* – a pre-processing phase, having the role to enhance the image, emphasizing the distinction between wound and non-wound.
- *Phase 2* – the main phase, having the role to analyze the image with the purpose to detect the edges.

For the phase 1 we implemented methods based on some convolution operators. Previously we applied for this phase some interpolation methods, using the pixel values. We performed a lot of experiments to compare the two methods and our conclusion is that convolution method is about 10% more efficient than interpolation method.

C. *Classification Methods*

Our work is based on a continuous collaboration with physicians and wound care experts, because it is necessary to make a rigorous classification for various categories of wounds. We collected large amounts of wound image data and we calculate statistical parameters as mean, median, standard deviation, confidence interval, skewness and kurtosis for them. These historical data are included in XML based databases, to be used as inputs to classification algorithms. The general purpose is to make distinction between infected and non-infected, inflamed and non-inflamed wounds. Based on color analysis, we build a statistically significant differentiation of mild, moderate and severe wounds. Our system analyses the differences in calibrated hue between injured and non-injured skin, obtaining a repeatable differentiation of wound severity for various time intervals. As an example, burn wounds are characterized according to their depth as:

- *Superficial* – with bright red color and the presence of blisters (usually with brown color).
- *Deep* – with red-whitish color and with dark dots.
- *Full thickness* – with creamy or dark brown color.

The system contains classification methods for classifying wound images into different groups based on colour and texture information. We investigated the suitability of statistical parameters for providing useful inputs to the classification algorithms.

Mean and Standard Deviation - Assuming normality, the first two moments (mean and standard deviation) characterize very well the color distribution. The mean represents the centre point of the distribution, separating the values into two equally probable subsets. Standard deviation represents the dynamics of the values, how wide around the mean the colors of the wound image are distributed. The first two moments (mean and standard deviation) are used to modify the contrast and the brightness of an image. The contrast is determined by the width of the distribution, while the brightness is determined by the location of the grouping color values [1]. We implemented Java programs that use the mean and standard deviation to modify and control both the contrast and the brightness of an image, by modifying the distribution of the color values. Fig. 4 shows the distribution of the color values contained in the original image (left), compared with the distribution contained in the modified image (right). In processed image, the contrast (width of the distribution) was increased by a factor of 2.0 and the brightness (mean value) was increased by a factor of 1.7.

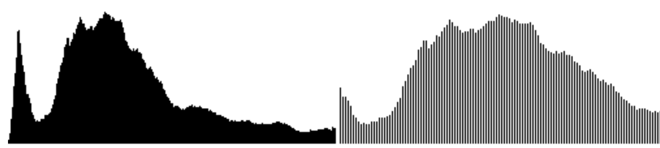

Figure 4. The distribution of the color values before processing (left) and after processing (right)

Skewness and Kurtosis - Sometimes the first two moments alone are inadequate to discriminate between wound and non-wound skin. Therefore further details of the color distribution are required. Skewness and kurtosis of the color data proved to be more useful for this purpose.

Skewness is a measure of the asymmetry of the distribution around the centre. Skewness is null for a normal distribution, positive when the distribution is skewed right (i.e. when the upper tail of it is predominant) and negative when the distribution is skewed left. If x is a random variable, we define the skewness γ_3 as the normalized third order moment, in the following way:

$$\gamma_3 = \frac{E[(x - E[x])^3}{(E[(x - E[x])^2])^{3/2}} \tag{1}$$

For a sample x_i (i = 1, 2, …, N), an estimate of the skewness is given by:

$$g_3 = \frac{\sum_{i=1}^{N} (x_i - m)^3}{(N-1)s^3} \tag{2}$$

where m and s are estimates of the mean and the standard deviation, and N is the sample size.

Kurtosis quantifies the flatness level of the distribution at the mean. Kurtosis is equal to 3 for a normal distribution. If kurtosis is lower than 3, the distribution is said to be platokurtic (i.e. wide-peaked) and if kurtosis is higher than 3, the distribution is said to be leptokurtic (i.e. narrow-peaked). The value 3 may be subtracted as an offset, as in the following formulae. For the same random variable x, kurtosis γ_4 is the normalized fourth order moment, being defined as:

$$\gamma_4 = \frac{E[(x-E[x])^4]}{(E[(x-E[x])^2])^2} - 3 \tag{3}$$

The kurtosis is used as a measure of the heaviness of the tails in a distribution. For a sample x_i (i = 1, 2, …, N), an estimate of the kurtosis is given by:

$$g_4 = \frac{\sum_{i=1}^{N}(x_i - m)^4}{(N-1)s^4} - 3 \tag{4}$$

We build in Java models for various categories of wounds, due to etiologies such as pressure, burn, chilblain, vascular insufficiencies, diabetic foot ulcer, venous leg ulcer and other chronic disease states. Based on color and texture analysis, we have to identify the main barriers to wound healing, such as tissue non-viable, infection, inflammation, moisture imbalance, or edge non-advancing. Our aim is to implement algorithms for wound healing simulations.

IV. E-LEARNING ENVIRONMENT

In a previous work we defined and implemented a Java framework for designing and implementing intelligent and practical e-learning tools, to be used by both the students and the teaching staff in a context of open learning. This framework provides the infrastructure for preparing e-learning scenarios based on practice and real world experiences, as practice is essential in learning activities. Our e-learning scenarios promote active learning, forcing the students to take part in real world activities simulated on computer. Also, we designed e-learning tools based on bootstrapping methods (which are quite valuable for reasoning in uncertain conditions), with the purpose to simulate laboratory experiments in both didactic and research activities. We rely on new paradigms of artificial intelligence (Bayesian Inference, Case Based Reasoning and Intelligent Agents) for creating e-learning scenarios to be used in a context of active learning. An e-learning scenario combines simulation and interactive visualization and allows the learners to explore the knowledge bases with some well-defined learning purposes. For each application object, our system contains a simulation class and a visualization class. These classes are then configured to obtain a particular simulation with a specific visualization. In an e-learning scenario, visualization is an active part of the system, serving as an additional interface for modifying dynamically some parameters. The simulation and visualization classes are coded in Java, using XML format to describe the configurations for both the components and their relationships.

An e-learning scenario is in fact like a traditional lesson, and the ideal solution is to simulate a teaching-learning relation with a virtual teacher able to interact with the learners and to instruct them [10]. A good traditional teacher learns all the time from previous didactic experiences. Based on this historical feedback, the teacher exploits prior specific successful episodes, and avoids prior failures. We introduce a similar feedback mechanism in our technology of elaborating e-courses (see Fig. 5). The feedback information, collected from learners' remarks and from prior results and successes, is stored in case bases. The relevant cases are retrieved and adapted to fit new situations from new e-learning scenarios, or to improve the previous ones. In addition, our approach in creating an e-learning scenario relies upon a special sort of goal oriented intelligent agents [6], able to incorporate knowledge, teaching methods and pedagogical characteristics into e-courses. We intend to implement a simulation of some intelligence based actions and initiatives, that are to be incorporated into e-learning scenarios, with the purpose to map, to plan and to monitor the pace and the progress of a learning process. Following the traditional model, the cases of positive experiences from previous e-learning scenarios are stored into case bases created with XML and CBR technologies [5].

This e-learning system is extended now with specific e-learning scenarios for medical education. Our aim is to create and implement in Java an automatic method which can be used as a reference standard for color and texture wound analysis. In collaboration with medical experts, we will create e-learning scenarios by applying the method illustrated in Fig. 5 to large amounts of wound image data stored in XML knowledge bases.

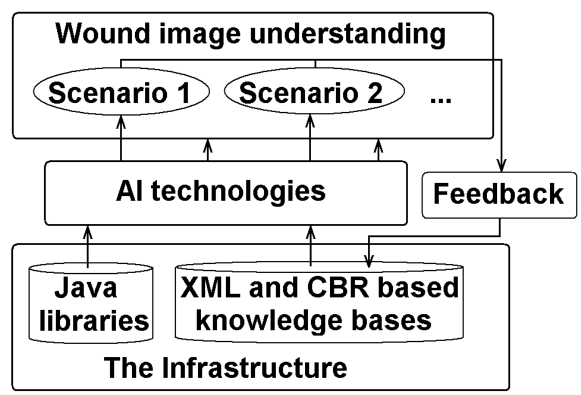

Figure 5. The generation of the e-learning scenarios

By estimating the percentages for the main colors of red, yellow and black, it is possible to assess the gravity of the wound. The image processing program allows the user to interactively control the process. The user can set the tolerance for each color, that is the width of the band of acceptable colors. Based on color analysis and statistical methods, it is possible to analyze successive states of a wound, assessing the wound healing evolution. The final goal is develop a flexible and adaptable system for wound image understanding, based on new paradigms of Artificial Intelligence (such as Bayesian Inference, Case Based Reasoning and Intelligent Agents).

The functionality of our system will aim to creating new e-learning tools, to be used by the students in medicine and pharmacy, at graduate, postgraduate and residency levels, for developing appropriate skills in wound management. Our effort is supported by a continuous collaboration with physicians and wound care experts from our university and from health care and medical units. We are endowed with a continuous access to actual medical records, allowing us to have in view the wound evolution and to verify the accuracy and the consistency of our system. The observed and the estimated values of the colors are all the time compared with each other. Based on color and texture analysis, it is possible to identify the main barriers to wound healing, such as tissue non-viable, infection, inflammation, moisture imbalance, or edge non-advancing. These results are used to implement algorithms for wound healing simulation. The advantage of using Java for this purpose is the integration without any difficulty with other Web based facilities.

The methods presented in this paper should be useful as an adjunct to traditional teaching and learning resources. In a context of blended learning, the teachers and learners may combine the color and texture based parameters with traditional parameters, such as smell, venous and arterial status, patient history, etc.

V. ELECTRONIC PORTFOLIOS

Our students have different backgrounds, interests, levels of motivation and approaching to studying, therefore we considered that open learning is adequate to them. The Java framework provides the infrastructure for preparing e-learning scenarios based on practice and real world experiences, as practice is essential in learning activities. Our e-learning scenarios promote active learning, forcing the students to take part in real world activities, simulated on computer.

To better the human contact between students and instructor, we approached new strategies labeled as blended learning, combining e-learning and traditional face-to-face classroom instruction, with a focus on active learning. We implement e-learning scenarios relying on learner centered paradigm, where learners are encouraged to develop skills and strategies in their own way. Learning is not considered simply as an outcome of teaching, because it is an activity having as input the results of teaching and training. Blended learning should be viewed as a fundamental redesign of the instructional model. A blended learning context can provide the independence and increased control essential to developing critical thinking. Along with the increased control that a blended learning context encourages is a scaffolded acceptance of responsibility for constructing meaning and understanding [4]. To be a critical thinker is to take control of one's thought processes and gain a metacognitive understanding of these processes, i.e. learn to learn.

In education, portfolios are described as a meaningful collection of students' work stored in a traditional folder [3]. There are various types of portfolios, organized according to the purpose they are used for:

- *Learning portfolios* – used for supporting the learning processes and the on-going professional development.
- *Teaching portfolios* – used for supporting the teaching processes.
- *Assessment portfolios* – used in evaluation processes.
- *Employment portfolios* – used in seeking jobs.

The electronic portfolio was introduced later and represents the same collection of students' work, only this time the storage is not the traditional folder, but an electronic storage environment, such as web pages, files organized in folders and stored on a CD or on a dedicated server, etc. [2]. Electronic portfolios take up little physical space, can hold a great deal of information and may be accessed with minimal effort. A learning portfolio is a collection of student work over a period of time, resulted from activities in the e-learning environment. In our framework, the learning portfolios consists of wound images and reports about wound healing, based on wound healing simulation scenarios, allowing to assess the wound image understanding. Electronic portfolios may improve the teaching-learning relation [9]. The students have a constant project to work on, being actively involved in the learning process, and their motivation has increased visibly. Both the teachers and the students agreed that portfolios provide a better assessment than the traditional testing: learners can have their learning process assessed and are offered the chance to reflect on their own work. Portfolios allow constructive feedback from tutors, increasing cooperative learning and students' motivation. Portfolio assessment helps students enjoy the assignments, while enabling them to learn more easily and take an active part in their development.

VI. CONCLUSIONS

This paper presents a Java framework for analyzing and processing wound images, to be used in teaching, learning and research activities. The color image processing methods have many advantages over traditional human methods in assessment of wounds. Computer based methods are objective, repeatable and with a large potential of processing. The analysis of a wound from a specific distance involves procedures devoted to identify its boundaries, to calculate its area and to estimate proportions of the main colors red, yellow and black. Generally, wounds have a non-uniform mixture of yellow slough, red granulation tissue and black necrotic tissue. To analyze the actual state of the wound and the healing evolution, it is necessary to determine the proportions of these main colors. We create XML based databases containing knowledge extracted from previous wound healing experiences and from medical experts' knowledge. The students create electronic portfolios, consisting of wound images and reports about wound healing, based on wound healing simulation scenarios, allowing to assess the wound image understanding. Our experience demonstrated that electronic portfolios may improve the teaching-learning relation. As a future work, we have to implement e-learning tools and e-learning scenarios enabling to perform quantitative measurements of wound evolution in time and to assess changes in wound healing, i.e. the recovery or worse evolution. This is our initial work towards a model of color and texture based simulation for the wound healing. We intend to simulate wound healing based on various treatments and to compare the results with experimental observations.

REFERENCES

[1] Baldwin, R. G., 2005. Processing Image Pixels using Java: Controlling Contrast and Brightness. Avail. (Last access at Feb. 10, 2009) at addr: http://www.developer.com/java/other/article.php/3441391

[2] Barrett, H. C., 2001. Electronic Portfolios. A chapter in *Educational Technology*, ABC CLIO. Avail. (Last access at Feb. 10, 2009) at addr: http://electronicportfolios.com/portfolios/encyclopediaentry.htm

[3] Farr, R. (1990). Setting directions for language arts portfolios. *Educational Leadership*, 48(3), 103.

[4] Garrison, D. R., Kanuka, H., 2004. Blended learning: Uncovering its transformative potential in higher education, *The Internet and Higher Education*, 7, 95-105.

[5] Leake, D. P., 1996. Case-Based Reasoning: Experiences, Lessons, and Future Directions (Menlo Park: AAAI Press / MIT Press).

[6] Nwana, H. S., 1996. Software Agents: An Overview, *Knowledge Engineering Review*, 11(3), 205-244.

[7] Prodan, A., Rusu, M., Campean, R. and Prodan R., 2006. A Java framework for analyzing and processing wound images for medical education. In Wolfgang Borutzky et al. (Eds.), *Proceedings of the ECMS 2006* (European Conference on Modelling and Simulation), pp. 421-426, ISBN 0-9553018-0-7, 28-31 May 2006, Bonn, Germany.

[8] Prodan, A. and Prodan, M., 1997. *Java Environment for Internet*, Editura Promedia-Plus, Cluj-Napoca, Romania, ISBN 973-9275-07-09.

[9] Rusu, M., Prodan, A., 2006. Electronic portfolios as means of improving the teaching-learning relation. In Ken Fernstrom et al. (Eds.), *Proceedings of the ICICTE 2006* (International Conference on Information Communications Technologies in Education), 17-21, ISBN: 1-895802-26-8, ISSN:1109-2084, 6-8 July 2006, Rhodes Island.

[10] Prodan, A, Rusu, M., Câmpean, R., Prodan, R., 2008. *Artificial intelligence for wound image understanding*. Proceedings of the ICEIS 2008 (International Conference on Enterprise Information Systems), pag. 213-218, ISBN 978-989-8111-48-7, 12-16 June 2008, Barcelona, Spain.