Wound Area Assessment using Mobile Application

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Keywords: Wound, Detection, Contours, Area, Mobile Device, Mobile Application, Wound Area Assessment, OpenCV, Java, Threshold, Image Processing, Color Histograms, Gauss Filter, Mobile Platforms, Android, iOS.

Abstract: This research aims to discover methods for the detection of the area of a wound using mobile devices. These devices have low memory and low processing capacity and they need the use of low complexity operations to identify a wound. The calculation of the wounded area consists of three phases, there are: image acquisition, image processing, surface reconstruction and calculations. This research is related to the use a mobile device to identify wound contours and area in a captured image. This image can be captured with a camera in a smartphone and the wound area is calculated based on the distance of the surface area and the resolution of the image captured. The main study in this research is the image processing in a mobile device, due to the limitations of these devices. However, the application developed during this research was developed for desktop, using the OpenCV library that is compatible with the Android platform and Java desktop technologies. During this research, the developed code written in Java will be easily adapted to the Android platform. The desktop application developed is available in a free repository for testing.

1 INTRODUCTION

The wound area assessment is an important research to estimate the evolution of wound healing and the healthcare professional can change the treatment of the patients (Ousey and Cook, 2011; Russell, 1999). Currently this topic is under a lot of research, but a method to estimate the wound area hasn't been discovered. This is a challenging task due to the complexity of the wound, variable lighting conditions and time constraints in clinical laboratories (Loizou et al., 2013). Wounds have some characteristics related to color and texture, but these characteristics aren't the same in all wounds images and people in the world. Therefore, research in this area hasn´t finished and future research can improve the wounds characterization. The research studies in this area have many purposes, such as verify the existence of a chronic wound, the existence of an infected wound, the origin of the wound and other aspects that classify and characterize a wound.

This analysis is related to the image capture and processing of a wound (Lazarus et al., 1994). The image processing and consequent wound area estimation has several phases, such as: image acquisition, image processing, surface reconstruction and calculations.

The image acquisition includes the process by witch the user makes use of a camera to capture a wound image. This process has some problems, such as ambient lighting, digital camera quality and resolution, as well as other problems. To minimize this problem, the next phase is image processing. This phase includes, the application of filters (blurring the images to minimize the imperfections of the images) and the thresholding of the images (converting the images to black and white, related to the pixel color intensity). In the next phase, some authors are doing the surface reconstruction, after the minimization of possible errors in calculations in the image-processing phase. In the calculations phase, the contours of a wound are identified and the wound area is the area within the contours.

This study is very important (Ousey and Cook, 2011; Russell, 1999), because it allows healthcare professionals to control their patient's state of wound healing and it can improve the treatment of

Miguel Pires I. and M. Garcia N..
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DOI: 10.5220/0005236502710282
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (SmartMedDev-2015), pages 271-282
ISBN: 978-989-758-071-0

wounds, which this occurs with a correct method and within a short period of time. In the 22nd annual meeting of the Wound Healing Society (WHS) held in 2012, the standards for wound healing procedures and proposed recommendations for evaluating optimal wound treatments were set (Loizou et al., 2013).

The challenge of wound area assessment is very complex, because the captured images contains various sources of environmental noise, which are difficult to control, such as lightning, contrast, distance to the objects and quality of images. Many people have done some research, but this research hasn't established a consensus in external factor correction in images. The research studies have a purpose to create an automatic algorithm, programmatically implemented and mathematically validated to calculate the wound area, but this research depends on the approach of the researcher to consider some variables or not. Manually, this research is complex too, because the wound area hasn't a defined geometric shape. Thus, in some cases of research without images, people preferred to measure the wound perimeter instead of the wound area.

Mobile technology is currently the most used and the mobile devices in current days have a camera with a good quality of image capture. Some devices have a proximity sensor. The presence of the proximity sensor allows the estimation of the wound area with better quality. Using a mobile device equipped with sensors the value of wound area calculated is more approximate to the real value. This purpose can be attained based on various programming languages and frameworks. To estimate the wound area there exist various methods for image processing. Initially, in this paper, it is analysed the wound area measurement using MATLAB with Image Processing library. Next, in this research is analysed the wound area measurement with Java language and OpenCV library compatible with the most used mobile platforms (i.e., Android and iOS operating systems).

This paper was organized in five sections. In section 2, other researches done by other authors are presented. In section 3, an overview of the methods for wound area estimation using images is described. Section 4 relates the wound images analysis and wound area measurement to mobile devices, presenting new methods or sensors utilization with these devices. Section 5 shows the conclusions of this research. At the end, the literature references used for this paper will be presented.

2 RELATED WORK

During the last years, various research authors addressed the wound area measurement and they have different perspectives about this topic. In general, research on this topic consists in the use of images to estimate the wound area measurement using a device (e.g., computer, laptop, smartphone or tablet) for image processing (Krouskop et al., 2002). Some research focuses in the use of other sensors, but it wasn't very investigated and validated. In relation to the use of images, the approach to this topic can be divided in some parts, there are: verification of a existence of a wound in the image obtained for image processing, identification of the contours of the wound and calculate the area between the contours (this corresponds to the wound area). This process isn't linear and objective and depends on the way the research authors view the problems. Some authors attempt to identify a wound with a relation to standard colors of wounds, other authors attempt to identify by textures and other authors use the join of standard features of texture and color of wound. Some research presents the identification of the existence of infection in a wound region and the type of wound.

This research area is important for the healthcare professionals to control, with an easy method, the wound-healing rate in a patient during the time of healing (Ousey and Cook, 2011; Russell, 1999). Thus, it allows a healthcare professional to verify the wound state and change the treatment used to the correct treatment related to the evolution of the wound healing. This is really important in chronic wounds (Casas et al., 2011; Papazoglou et al., 2010), because the area of this type of wounds doesn't decrease constantly during the wound healing time and it can increase and decrease inconstantly during the time of wound healing. The chronic wounds are more frequently in elderly people, diabetic people or people with chronic diseases. The health defences of these people are weakened and their wounds take longer to heal.

Thus, some research authors have done various studies related to this topic. The wound-healing rate is primarily quantified by the change of wound area and the authors attempt to define a standardized and objective technique to assess the progress of wound healing, by means of texture image analysis (Loizou et al., 2013). The texture of wounds depends of the location of wounds in people's body. In the studies done by the authors of (Loizou et al., 2013) some tasks where done related to the image processing, these were image pre-processing, segmentation, texture and geometrical analysis together with visual expert's to assess the wound healing evaluation. These authors use a total of 77 digital images collected in 11 different subjects with foot wounds. These images were taken every third day, for 21 days, by an inexpensive digital camera under different lighting conditions (Loizou et al., 2013). The images collected were intensity normalized, and wounds were automatically segmented using a segmentation system based on snakes. With these experiments, the authors of (Loizou et al., 2013), in order to identify features that quantify the rate of wound healing, had extracted 56 different texture features and 4 different geometrical measures. Thus, the authors of (Loizou et al., 2013) discovered that the texture features indicate the progression of wound healing and some texture features increase (mean, contrast, roughness and radial sum), while some other texture features decrease (sum of squares variance, sum variance, sum average, entropy, coarseness, EE-laws texture energy measures and the Hurst coefficients for fractal dimension one and two analysis) with the progression of wound healing process. When they compare the different features at two different time points during wound healing process, they access the rate of wound healing, but the comparison of all geometrical measures extracted from wounds at two different points doesn't present important information about the wound healing. So, these authors create a simple method that uses some texture features to monitor the wound healing process, to reduce costs, provide standardization and improve the treatment quality for patients and provide a valuable tool in clinical wound evaluation (Loizou et al., 2013).

Related to the importance of wound healing control in chronic wounds (Russell, 1999), the authors of (Papazoglou et al., 2010) present a new algorithm implemented in MATLAB software validated in, approximately, 50 animal images and 100 human images. The images for the tests were captured with a common inexpensive digital camera and in various lighting conditions. These authors make a comparison of results in animal images and human images and compare the manual wound boundary (obtained in Adobe Photoshop) and the automatic wound boundary (obtained in MATLAB software), obtaining very small errors in wound area measurement. This research depends of the resolution of the processed wound images, but the authors of (Papazoglou et al., 2010) proposed and evaluated a highly accurate algorithm for wound segmentation which requires a minimal manual input by using a combination of both red-green-blue (RGB) and L*a*b color spaces, as well as a combination of threshold and pixel-based color comparing segmentation methods.

Other authors have developed systems with automatic algorithms to measure various parameters of wounds, such as area, perimeter, width and height of wounds using images. A example of a system developed by authors of (Plassmann and Jones, 1998) is the MAVIS system used to automatically measure the dimensions of skin wounds. In this system, the method of measurements is based on color segmentation algorithms and this method is able to segment images related to healthy skin, wound tissue and epithelialisation tissue. The method considers the RGB color planes, hue, saturation and grey-level intensity. The RGB color planes were only examined in isolation, showing that straightforward thresholding of color planes cannot produce a good segmentation, which distinguishes between wound and skin tissues. The wound segmentation with this method is only partially successful if only the one-dimensional color histograms were taken into consideration, while using a 3-dimesional (3D) RGB histogram space, the color volume clusters may be more widely separated and a better segmentation result can be achieved. Some authors, such as (Mekkes and Westerhof, 1995; Nayak et al., 2009; Wannous et al., 2008; Wannous et al., 2007), consider they made some progress using 3D RGB color histogram clustering technique to assess the wounds healing. The research of (Mekkes and Westerhof, 1995) shows that clusters in RGB space for a given tissue type formed an irregularly shaped 3D cloud, and therefore simple thresholding along the R, G and B axis wouldn't help to segment the image into some tissue types. The segmentation of wounds in color images based on the use of the black-yellow-red classification scheme to evaluate the debridement activity of wounds have some techniques presented by other authors (Gammal and Popp, 1995; Gallagher, 2012). The segmentation of wound images consists in the image-processing phase.

The method of pre-processing images corresponds to the first phase of wound area measurement. The second phase consists in the identification of contours of wounds, but some research join the first and second phases and in the first phase (corresponding to the segmentation, threshold and other tasks for pre-processing images) identifies the contours of the wound. The Support Vector Machine classifiers (SVM) can be used to perform region segmentation of the wound tissue followed by extraction of the contours of the wound (Kolesnik and Fexa, 2004). In the study presented in (Kolesnik and Fexa, 2004), the authors used 50 RGB images, which were manually delineated by experts as training data, and then tested their method using 23 new RGB wound images. The SVM algorithm used by (Kolesnik and Fexa, 2004) was able to correctly classify roughly 94% of the pixels as either wound or non-wound, compared with the expert's manual tracings.

Many research used SVM algorithms (Kolesnik and Fexa, 2006) with various purposes on this topic. Authors of (Giger et al., 2008) start using a 3D model for wound measurements using uncalibrated vision techniques and a color classification wound tissues, combining shape and color analysis in a single tool for real tissue surface measurements. A database with images of different tissue types in uncontrolled lighting environments was created (Giger et al., 2008), applying a correction method to reduce color shifts. The problem unsolved by all authors researching in this topic is the difficulty to control environmental conditions in the experiments and in the use of the system by other people. Then, color and texture tissue descriptors are extracted from tissue regions of the images database, for the learning stage of an SVM region classifier, and apply unsupervised color region segmentation on wound images and classify the tissue regions. The SVM algorithm used by (Giger et al., 2008) obtains an overlap score in the result of automatic segmentation driven classification, (66 % to 88%) of tissue regions higher than that obtained by clinicians.

Multidimensional color histograms in SVM classifiers for automatic extraction of wound region from an image are used in some research (Kolesnik and Fexa, 2005). The authors of (Kolesnik and Fexa, 2005) compare the performance of the multi-dimensional histogram sampling with several existing techniques for quantization of 3D color space and this increased the performance of wound segmentation by about 25%. Many research authors researched about the creation of systems to measure size and tissue type of wounds, using images taken by a digital camera and complex systems were created. For example, the system constructed by (Wild et al., 2008) takes about 90 seconds per lesion and, if the user needs a report with suggestions for therapy, the system needs 4 minutes.

Instead of the use of SVM classifiers, some research uses Artificial Neural Networks (ANNs) algorithms (Acha et al., 2005; Navas et al., 2013; Song, 2012; Song and Sacan, 2012), such as the Multi-Layer Perceptron (MLP) and the Radial Basis Function (RBF) with parameters determined by a cross-validation approach. There are then applied with supervised learning in the prediction procedure for the wound identification, and their results are compared. The results obtained with ANNs are satisfactory and this reveals that this method can, in the future, improve the techniques of wound area measurement and identification, making it a promising tool to assist in the field of clinical wound evaluation.

The automatic systems for wound area measurements are very useful for telemedicine systems, because the patient can send a digital photography to the system and the healthcare professional is able to check the patient's wound state and change the treatments at distance (Wannous et al., 2010). These systems need to allow for practical image acquisition conditions, such as digital camera type, lighting, and viewpoint of wounds. In general, the telemedicine system consists in a website or platform for users/patients and professionals interaction. The systems presented in (Wannous et al., 2010) were obtaining results of 79.3% between classified tissues and the medical reference, which compares favorably with the average score of 69.1% obtained by a single clinician during the validation tests. The research authors conclude that these systems are very important for improving the health treatment in a world with more people. These systems are very useful for e-learning systems, because the use of Web platforms allows to explaining this topic to the students. The e-learning systems apply the techniques present in some research and consider the phases of image processing already present. These systems improve the teaching-learning relations and provide a better assessment among students than traditional methods (Prodan et al., 2010b). All systems implemented are Web-based (Kim et al., 2003; Prodan et al., 2009) or software developed in MATLAB software or in other programming languages, such as the Java programming language (Cuautle, 2007; Prodan et al., 2009; Prodan et al., 2006; Prodan et al., 2010a) and others, using various frameworks. These systems for classifying the wounds, in general, comprise four phases, and these are (Kumar et al., 2013): pre-processing images, image segmentation, feature extraction and classification. At the end of this, the system will be able to measure the wound area and other features of wounds. The web-based systems (Kim et al., 2003, Prodan et al., 2009) consist in three-tier layer system for the user to send a digital image and the image is processed in a server, showing the results of wounds area during the time of wound healing.

Other authors (D, 2006) developed a desktop application in the VB.NET language for Microsoft systems. This algorithm consists in various steps, these are: the digitalization of the outline (perimeter) of an image from right to left, the digitalization of the outline (perimeter) of an image from left to right, the digitalization of the outline (perimeter) of an image from top to bottom, the digitalization of the outline (perimeter) of an image from bottom to top and, finally, the calculation of the area enclosed by that outline. This system has an objective to use a database and it consists in a non-invasive, accurate, consistent, efficient and easy wound measurement system.

The differential evolution method for estimating the wound healing is used in some research and obtains best results. This method uses the K-Nearest Neighbor (KNN) algorithm to classify the wound healing. This method includes many phases, there are (Aslantas and Tunckanat, 2007): read image, detect entire wound, fill gaps, dilate the image, fill interior gaps, remove connected objects on border and smooth the object. This method obtains good results during the validation tests and it obtains very low errors.

The planimetric techniques for assessing the wound area and perimeter with reliability and low errors are used by authors of (Mayrovitz and Soontupe, 2009). The automated systems are very important for a correct wound area measurement, because, in some cases, the manual measurement is very difficult.

Nowadays, the use of smartphones equipped with camera and various sensors is very common the people and these equipments are practical for wound measurement (Wannous et al., 2011; Cuautle, 2007; Foltynski et al., 2013; Hettiarachchi et al., 2013; Perera and Chakrabarti, 2013; Sikka et al., 2012). These devices can improve the telemedicine techniques and treatment at distance (Vivanco et al., 2011). The mobile applications structure is the same of desktop applications using frameworks designed for the wound area measurement. In general, the captured images are sent to an images database to improve the reliability of the method and send the processing tasks to the server that has more capacity to do complex tasks of image processing. These applications can apply all research studies already presented, but the user can access to the wound area over time in various places. These systems have the same problem of digital images, because all variables in the environment are difficult to control. In fact, the use of these practical devices is low-cost and it will be able to adapt in hospitals for correct and practical measurements, because, in recent days, the research in this topic has improved. Recently, many authors developed various frameworks to estimate the wound area using the Java programming language (Cuautle, 2007), and XML (eXtended Markup Language) descriptors (Prodan et al., 2009; Prodan et al., 2006) as reference, for Android platform or other mobile platforms. The mobile health improves the treatments in various areas, such as control of a healing wound and the patient's health state in various parameters (Friesen et al., 2013, Perera and Chakrabarti, 2013). For desktop applications, mobile applications or web-based applications, this needs a study and development of a framework for the programming language used and an image descriptor (in general, it is defined in XML) for classifying the images. This work is very difficult, because images have many features, such as granularity, texture, color and the wounds depends of various factors.

In current days, many applications, frameworks and methods have been developed and are in advanced research state. The tracings of the Visitrak method were quick, easy, and inexpensive to perform and noninvasive for the patient (H et al., 2009). The Visitrak method considers the foot curvature and removed the subjectivity associated with manual square counting. The method was both valid and repeatable in the measurement of wounds > $25mm^2$ in size. The Pressure Ulcer Scale for Healing tool was designed to track pressure ulcer healing by monitoring wound parameters of length times width, exudate amount and tissue type (H et al., 2009). The PSST system was designed to describe wound healing in pressure ulcers, consisting of 15 scored (used to assess variables of wound size and depth, tissue characteristics and wound exudate, whereas the non-scored items examined wound location and shape) and two non-scored items (H et al., 2009). The Sessing Scale is a seven-stage scale designed to measure progress in wound healing over time, with each stage describing wound tissue attributes throughout the wound healing process (H et al., 2009). The Sussman Wound Healing Tool is based on an acute model of wound healing, which describes tissue status and size throughout the wound healing process (H et al., 2009). Other mobile application for mobile devices is MOWA (Mobile Wound Analyzer) (Healthpath, 2011). MOWA differentiates types of tissues found in pressure ulcer, analyzes photos taken with the on board camera or uploaded pictures from other sources, identifies three types of tissues in the bed of the lesion (necrotic, fibrinous and granulation) and calculates the area of the lesion and indicates the treatment. WoundRight (Technologies, 2013) is an other mobile wound care application that offers advanced wound, ostomy, and continence documentation with the ability to add individual treatments, and perform detailed assessments. WoundRight (Technologies, 2013) performs a powerful accurate and consistent assessments for wounds and generates progress, area and dimension charts of wounds and calculates and analyzes wound data to drive better care and better results. These applications improve ulcer therapy, telemedicine, assistance quality, follow up of the cure, communication, collaboration, home care assistance and medical/nurse training and education, reducing use of ineffective products, care times and hospitalization time.

The next sections present some methods of wound area estimation using images and the inclusion of the use of mobile equipments for executing this analysis of wound area.

3 METHODS OF ESTIMATION OF WOUND AREA USING IMAGES

The estimation of wound area has already a lot of research focus on the use of images for creating automatic algorithms to identify the wound and estimate the wound area. For this process, various research identify a lot of methods to estimate the wound area with more or less accuracy and reliability, depending of the research authors. In this section, a lot of methods of estimation of wound area using images are described.

The methods of estimation of wound area are part of software implemented in desktop and mobile applications and exists various types of methods. The process of the methods researched can do automatic or manual procedures to identify the wound area and measure the wound area.

The basic method of wound area measurement consists in the phases focused by other authors in other research studies presented in the section 2. So, after segmenting images by color or texture or a mixed segmentation by color and texture and consequent wound contours detection, the results of wounds area are in an enclosed contour over the area of the plain image (Hettiarachchi et al., 2013). In order to calculate the enclosed pixel area, a flood fill is used to separate internal and external pixels (Hettiarachchi et al., 2013). After this process, histogram method, that consists in separate the colors by intensity, is used to calculate the number of pixels within the wound, which is then scaled to the actual size using the initial calibration triangle (Hettiarachchi et al., 2013).

A free hand (FH) drawing (Van Poucke et al., 2010) method is based on the simply holding down of the mouse button and dragging to draw the margin of the wound bed. In fact of the difficulty to calculate the wound area, this method was compared with other method in (Van Poucke et al., 2010) and the mean of two wound area values obtained by two methods is considered the approximated value of the wound area. The method used in the comparison is a method based on a closed polygon (CP) (Van Poucke et al., 2010) graph algorithm, which is a technique where the margin of the wound bed is drawn with multiple lines that eventually meet. For this comparison, the authors of (Van Poucke et al., 2010) used a set of 2285 images of wounds and any method that is considered clinically accepted, because the values are very different, as it is possible see in figure 1.

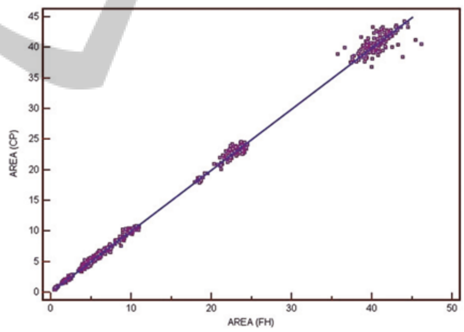

Figure 1: Correlation of area measured with free hand and closed polygon with line of equality (Van Poucke et al., 2010).

In figure 1 is possible to view that the wound areas identified differs in the use of free hand drawing method and a closed polygon graph algorithm. So, these methods are acceptable to some healthcare professionals, but not accepted for others, because these methods obtain large errors in wound area measurement.

The other computer-aided method for wound area measurement consists in the use of tools related to the image processing, such as Adobe Photoshop, to open a JPG image, defining manually the border of wound in image and calculate the pixel value of the region selected as wound and record this to a Microsoft Excel sheet (Li et al., 2012). This process is repeated and some independent research authors statistically measure the values of wound area based on the values in the sheet. The traditional transparency-based wound healing assessment is an efficient method and clinically accepted by healthcare professionals (Li et al., 2012). This method uses a transparency film for marking out the margins of individual wounds. The outlines regions as well as the suitable standard area control(s) were cut off along the margin with an electronic cutter and weighed by an analytical balance and the weights of transparency pieces were converted to the areas one by one by dividing the weight of the checked region (Y) with the weight of standard unit (X) and then times the known area of the standard unit (Z), applying, in the end, statistical corrections for the obtain a better wound area measurement (Li et al., 2012).

The chronic wounds have very irregular dimensions and various methods created aren't very accurate. But, for chronic wounds, it is important to control the wound healing. Thus, a reasonable approach to determining wound size during a brief patient encounter would be to document the wound's linear measurement – that is, perpendicular linear dimensions (D, 2006). Normally, in the wound's linear measurement, the researchers measure a wound as a shape, such as a rectangle or an ellipse. The area of an ellipse is calculated by measuring two perpendicular diameters, such as maximum diameter (major diameter) and maximum diameter perpendicular to the first diameter (minor diameter) (D, 2006) and this area have an error between 16% and 40% of the real area (Casas et al., 2011). This method is simple and relatively cheap, but the method isn't precise, because it assumes the wound area as a simple shape and the wound can have an irregular form (D, 2006). By other research authors, this method is called ruler based method (Nemeth et al., 2010). If the area selected is a rectangle, the area may be overestimated by 10% to 45% with less accuracy for smaller wounds (Casas et al., 2011).

An other method consists in the placing of a transparent film over the wound and tracing the outline with a permanent marker (Casas et al., 2011, Nemeth et al., 2010). After this process, the transparent film is placed on a metric grid and the area is calculated by counting the number of squared millimeters contained within the outline (Casas et al., 2011). This method has a large probability to have a human error in tracing and the trace is subjective, depending of the person that does the trace (Casas et al., 2011). After this, the area can be measured with a digital photography of the transparent film with the trace to measure the value of wound area (Casas et al., 2011). The wound area can be estimated with a planimeter (Nemeth et al., 2010).

Other vision-based techniques use either stereophotogrammetry (SPG) or structured lighting to obtain wound images (Nemeth et al., 2010). For stereophotogrammetry, two or more photographs of the same wound are taken from slightly different angles and the photographs are used to produce a 3D model of the wound in a computer (Nemeth et al., 2010). Then, a computer traces the wound border and the wound area can be calculated.

Various research authors attempt to create an algorithm to estimate the wound area using images, but all methods have influence of external factors, such as lightning, shadow, and others, in the image and these cause errors in wound area estimation. Despite errors, some algorithms are clinical accepted to help the measurement of wound area.

In the next section, this document will explain how to use mobile devices, such as smartphones, tablets and other hand-held devices, for the estimation of the wound area and the methods, languages and frameworks, which is possible to use.

4 WOUND AREA ESTIMATION USING A MOBILE DEVICE

In the last decade, the use of mobile devices has been increasing, because these equipments experienced a reduction in price and an increase of memory and processing capacities (Heggestuen, 2013). Now, one in every 5 people in the world own a smartphone and one in every 17 people own a tablet (Heggestuen, 2013). The two platforms responsible for the largest market share are Android operating system (owned by Google) and iOS operating system (owned by Apple) (Bosomworth, 2013). Smartphones usually integrate various sensors to perform tasks that are related to the use of the phone in a telecommunications or multimedia-browsing context, such as camera, accelerometer, proximity sensor and others. These equipments allow the user to do complex tasks in movement without dependency of a desktop computer, because these equipments can connect to the Internet to send data for processing tasks that needs a server for remote processing, storing into a remote database and visualization of remote data processed.

These devices have a lot of applications available in the online application stores, to manage and processing data and do other tasks. Applications related to the wound area measurement are low, because it is very difficult to measure the wound area and various research don't have a consensus about the wound area measurement techniques. Generally, these equipments have a capacity to take photographic images of a wound with the embedded camera in the smartphone. Recently, various research authors saw the benefits of the use of smartphones for wound area measurement and a lot of research was done in this topic. The two mobile applications available in application online stores about wound area measurement are MOWA (Mobile Wound Analyzer) (Healthpath, 2011) and WoundRight (Technologies, 2013).

MOWA is a non-invasive software that makes use of a camera of a smartphone to allow the user to take photos or upload photos of the wound to analyze, differentiating the types of tissues (necrotic tissue, fibrinous tissue and granulation tissue) and calculating the wound area and indicating the treatment. This application does some tasks automatically and other tasks are manual (needs human interaction). The manual tasks are taking a photo, designing the mask, setting parameters and sending a JPG and PDF file via e-mail. The automatic tasks are analyzing tissues, calculating the wound area, defining directions/suggestions in treatment and creating an analysis report in PDF. MOWA is registered as a medical device, is fast (analysis process takes less than 3 minutes), is easy to use, improves ulcer therapy, improves the quality of assistance, helps to identify and measures the ulcer tissues, defines the priorities in treatment, suggests the therapeutic treatment, improves the follow up of the cure, automates the clinical documentation, improves the communication and collaboration, helps medical/nurse training and education, facilitates sector study investigations, eases effectiveness monitoring of new products, reduces the use of ineffective products, reduces care times, reduces hospitalization time, supports home care assistance and supports telemedicine. Figure 2 shows the screen of application, calculating the wound area of a digital image uploaded to the application and using the automatic method of measurement. MOWA application is only for iPhone and it is paid.

WoundRight is a software application that offers advanced wound, ostomy, and continence documentation with the ability to add individual treatments, performs detailed assessments and brings convenient and immediate wound care to the patient. This application takes the tablet anywhere and collects your data with or without the Internet, performs powerful, accurate and consistent assessments for wounds, generated progress, area and dimension charts, shares patients data securely with their affiliated accounts, tracks vitals, medical conditions, and report on open or closed wounds, calculates and analyzes wound data to drive better care and better results, reduces redundancy, keeps compliant, improves revenues and decrease wound care costs by lowering re-hospitalization rates and increasing referral rates and decreases maintenance costs. WoundRight application is only for tablets, is supported for Android and iOS operating systems and it is free.

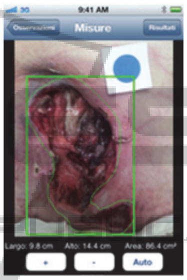

Figure 2: Screen of MOWA application calculating the wound area (Healthpath, 2011).

Many other research studies exist about the wound area measurement related to mobile devices. These authors define algorithms implemented in various programming languages and use various frameworks. The Android development should be done in Java programming language and in this programming language exists a lot of studies, frameworks and libraries available for wound image processing to measure the wound area. The iOS development should be done in Objective-C programming language and in this programming language exists a minor number of studies, frameworks and libraries available for wound image processing to measure the wound area.

The study presented in (Hettiarachchi et al., 2013) consists in an application, implemented for the Android operating system, to provide a practical fast and non-invasive technique to monitor the wound healing process. The process starts with the pre-processing of an image captured with camera of the mobile device. In pre-processing phase, the active contour is predefined and centered on the wound, cropping is utilized for centering the wound. In this phase, the unnecessary artifacts such as clothing, limb borders and backgrounds are removed and users demarcate the crop section by marking the diagonal points of a rectangle on the device's touch screen. Next, all images are resized to 500 pixels, but maintain the original ratio. Finally, in this phase, the saturation plane of the HSV color model is extracted as the base for the active contour algorithm since it displayed the best contrast between infected and normal skin and the image is further smoothed using a Gaussian filter of 31x31 dimensions with σ=5 in order to remove artifacts that may have otherwise attracted the active contour erroneously. The next phase corresponds to the segmentation of the image. The segmentation is based on active contour models, which identifies the wound border irrespective of coloration and shape, and the user, providing higher control and accuracy, can modify the segmentation. Finally, the wound area measurement is further normalized to remove effects of camera distance and angle and the area corresponds to the area between the contours. The results obtained in this application have an accuracy level of 90%.

The mobile applications for estimating the wound area have a lot of research that explain the benefits of these applications (Perera and Chakrabarti, 2013; Friesen et al., 2013; Casas et al., 2011). About the method analyzed in the section 3, ruler measures and transparency tracings were used by authors of (Nemeth et al., 2010) for measuring wound size often have low accuracy and reliability and they created a new method used in a wound measurement device (WMD) designed by them. The device designed in (Nemeth et al., 2010) allows the wound area measurement with to assess for accuracy over distance from the wound surface, as well as camera angle skew, using the inter-rater and a intra-rater methods. Both intra-rater and inter-rater reliability proved to be significantly higher than conventional methods, such as ruler measures and transparency tracings and these methods have an average 2.65% error rate in the accuracy measurement based on two black and white shapes with known areas. The two methods that used a rectangular approximation of area had positive bias meaning that they typically over-estimated the area, whereas the two techniques that traced the borders under-estimated the areas (Nemeth et al., 2010).

Usually, the process of wound area measurement using a mobile device consists in three main phases, these are (Andrade et al., 1999, Gonzalez and Woods, 1992; Zaffari, 2006): image pre-processing, image segmentation and wound area measurement. In the image pre-processing, to obtain better results of the contours, a filter for remove the noise is applied, such as the Gaussian Blur. After applying the filter, the adaptive threshold should be done to convert the image to black and white colors. Next, the dilate operation is applied to fill the cracks. After these three tasks, closed contours can be achieved. For wound area measurement exists a framework, developed for all platforms in the market to do the image processing with easy methods. This framework is named OpenCV (Bradski and Kaehler, 2008; Marengoni and Stringhini, 2009) and it allows to do the tasks referring to pre-processing image phase. In the image segmentation phase, this framework has methods to identify the contours of a wound, using various algorithms, such as Canny Edge Detection or others. And for the end phase, this framework has a method to calculate the area between the contours. So, the use of OpenCV framework is easy and facilitates the tasks for wound area measurement. This is compatible with Android applications (developed in Java) and iOS applications (developed in Objective-C). Other frameworks are developed in the Java programming language (Cuautle, 2007; Prodan et al., 2006) and can be adapted to mobile applications for Android operating system.

Most of all methods researched for desktop applications can be adapted to mobile device applications (Friesen et al., 2013) and have possibility to estimate the wound area, processing the image on the device, after capturing the image with the embedded camera, or sending to a server, via Internet, and the image processing will be performed remotely (Foltynski et al., 2013; Sikka et al., 2012; Vivanco et al., 2011). The user can see the results on the device, such as AreaMe (Foltynski et al., 2013), that the results was compared with the results of Visitrak and SilhouetteMobile (Wannous et al., 2011) systems.

The use of mobile technology increases the ease and accuracy in monitoring a wound treatment. This is especially important in chronic wounds, because they require greater control and adaptation of treatment. This is a topic that is in constant investigation and evolution to improve the existent methods.

At the end of this research, a Java Desktop application was available at a free repository and the source code is available for future research studies.

5 CONCLUSIONS

In conclusion, the wound area assessment is a good topic for research, because in the last years there have been some improvements, but the algorithms developed in some cases have big errors. The existence of a lot of research indicates that this research in this topic isn't ended and is a very interesting research.

The research of the wound area assessment can be done manually (low precision) or automatically (in the last years has a evolution in this methods). To manually process for wound area measure, the healthcare processional use metrics to measure the wound area, which commonly is measured as a geometric form, such as a rectangle. For automatic process, the healthcare professional uses software for image processing that identifies a wound based on color and/or texture of wound images. The wound image characteristics are stored in a database for future comparisons. This process is done in three phases, these are: image pre-processing, segmentation and wound area measurement.

In the image pre-processing phase is identified the existence of a wound in the image, by color histograms or texture comparisons and the image needs to be applied a low-pass filter, threshold and dilatation of image to obtain a closed contour. To verify the existence of a wound in the image a K-NN or a SVM algorithm is applied for the verification.

In the segmentation phase, the contours of the wound image are identified. For identify the contours various methods exist, for example using a geometric shape, discarding some parts out of the wound or identify the pixels by the color.

For the wound area measurement phase, the result obtained is the area between the contours. This research is very important especially for the area of chronic wounds, because these wounds need to be monitored during the healing time, because this area doesn't decrease constantly during the healing time.

The use of mobile devices allows the wound area measurement with better precision, because is good to identify the camera distance of the wound, so it allows to estimate the real wound area anywhere in movement, using a proximity sensor of the mobile device. For the process to estimate the wound area in a mobile device, various frameworks exist in various programming languages for help to the development of the applications, such as OpenCV framework and others.

This research is very difficult, because is not possible to control some environmental variables, such as lightning, noise and quality of camera, but some algorithms implemented are clinically accepted to help the healthcare professionals in telemedicine. The wound image processing in mobile device can be done with processing image in the application or send the image by Internet to a server and receive the results data in the smartphone.

As future work, this research topic needs to be continuing improve for these applications can be used commonly in a hospital to improve the treatments of the patients. The use of automatic systems has advantages and disadvantages, but normally the use of automatic systems is more precise than manual measurements.

ACKNOWLEDGMENTS

This work was supported by FCT project**PEst-OE/EEI/L A0008/2013** (*Este trabalho foi suportado pelo projecto FCT PEst-OE/EEI/LA0008/2013*).

The authors would also like to acknowledge the contribution of the COST Action IC1303 – AAPELE – Architectures, Algorithms and Protocols for Enhanced Living Environments.

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