WoundArch: A Hybrid Architecture System for Segmentation and Classification of Chronic Wounds

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Abstract: Every year, millions of people are affected by wounds worldwide. The wound treatment process is costly and requires the nurse to perform activities during patient care: tissue classification and calculation of the wound area. Thus, this work proposes to build a hybrid computer system with two configurations to support wound care. The first configuration uses a smartphone to perform the capture, segmentation and classification of the wound images. The other configuration has a client-server architecture, the images are captured and segmented in the application and sent, via the internet, to the web server, which is responsible for classifying the tissue of the wounds. The proposed methodology is the segmentation of images using the watershed algorithm and classification of tissues in Necrosis, Granulation or Crushing. fulfilled. To evaluate the application, experiments were performed with 20 images of wounds and the system was evaluated in two architectures: client and client-server. The results show that the client-server reached accelerations of up to 3.2 times in relation to the client-only architecture. The client-server architecture also saves energy and space in the client units, increasing the uptime of smartphones, in addition to reducing the storage load of the same.

1 INTRODUCTION

A wound is an interruption in the continuity of tis- sues by external mechanical force by physical force, but also damage by heat, cold, chemicals, electricity and radiation (Pounder, 1969). Wounds can be clas- sified, according to tissue repair time, in acute and chronic (Whitney, 2005). Acute wounds are those that heal in a timely manner and without complications, while chronic wounds take longer to heal due to their extension and severity, and usually present inflammation in the wound tissues (Clark, 2014). The causes for their existence are usually associated with pre- existing diseases (comorbidities), such as diabetes and venous insufficiency, for example, and complications such as infections that hinder the healing process. Wound is a worldwide health problem and affects a large number of people, compromising their quality of life. According to Sen et al. (Sen et al., 2009), annually, in the United States alone, as chronic wounds affect 6.5 million patients, generating an estimated expenditure of U$ 25 billion annually in the treatment of chronic wounds; In the Netherlands, annual costs for pressure ulcer treatments range from U$ 362 mil- lion to U$ 2.8 billion, representing 1% of the Nether- lands budget (Brem and Lyder, 2004). These figures indicate the magnitude of the problem with significant socioeconomic repercussions. Chronic wound treatment incur into high costs for health services and the patient, especially when referring to chronic wounds due to increased prolongation of treatment (Nussbaum et al., 2018).

The nursing process (Garcia and Nóbrega, 2009) guides the performance of these health professionals through steps that should be developed during patient care, namely: collection of nursing data, nursing diagnosis, nursing planning, implementation and

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evaluation. In the context of wound treatment (Kordestani, 2019), this process can be specialized as follows: the professional begins analyzing the patient's health history, wound history and previously performed treatments; then it analyzes the current state of patient health conditions and wound conditions (tissue types, size, location, etc.) to make a diagnosis. Subsequently, the professional performs wound and scar treatment, possibly with debridement, cleaning, med- ication (or equivalent intervention) and maintenance of moist tissue. Finally, the nurse performs the procedure of the coverage necessary for the wound and records the information about the treatment (Figure 1).

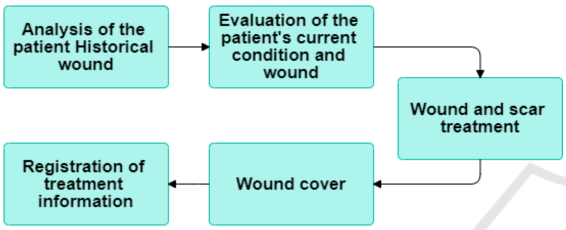

Figure 1: Steps of the nursing process.

In the context of wound treatment, one of the fundamental steps to arrive at a diagnosis is the identification of characteristics of the lesions, such as: the causal agent, the depth, the shape, the size, the amount of exudate, the location, the appearance and treatment environment (Dealey, 2008). Also according to the author, the objective of the evaluation is to extract information about the stage of the wound and, consequently, its follow-up based on the organism's response to the treatment being performed. The correct identification of these variables is highly dependent on the professional's expertise. In this way, it is based on the individual ability to visually assess how injuries have been shown to be susceptible to errors.

In this context, in order to reduce human limitations, computer systems have received great attention as a work tool in the health area, mainly for the power of information processing, for the ability to work with a large volume of information and for the convergence between media and devices. This type of sup- port provides greater precision and agility at work, helps, personalizes and expands the activities to be performed by health professionals (Tibes et al., 2015). In the literature, it is possible to find some studies that present proposals for informational systems that sup- port wound care.

Different scientific studies have been developed focusing on the use of smartphone-web server plat- forms in nursing diagnoses in patients with wounds. Wallis et al. (Wallis et al., 2016) shows the use of a mobile application that captures images of wounds due to burns and sends them to the server so that doctors can evaluate and make the diagnosis. Sir- azitdinova and Deserno (Sirazitdinova and Deserno, 2017) describe a wound assessment system that uses a smartphone device to capture images and a server that processes, stores and reconstructs wounds in 3D models.

In this work, we propose the use of a client-server application to perform a necessary need for chronic wounds, a classification of their tissues in splinter- ing, granulation and necrosis. The construction app will allow not only to support wound assessment, but also offer a tool that will help prevent complications that can result in early amputations. In addition to facilitating the work of nurses in the classification of wound tissues and presenting the data regarding the injury in an appropriate way. Nursing professionals increasingly have mobile devices that allow them to capture images of wounds. Thus, knowing and im- proving the efficiency of processing wound images on mobile devices is essential for scientific knowl- edge to reach the market and make sense in the reality of nursing professionals. The literature still lacks re- search that evaluates the execution time and battery consumption of wound segmentation and classifica- tion systems on mobile devices.

2 RELATED WORK

During the development of this project, several systems that have similar objectives to those proposed in the work were studied. At this stage, some of the systems found in the literature will be described, pointing their practical motivations and their respec- tive limitations. In particular, we consider the works of (Cohen and Bard, 2015), (DigitalMedLab, 2019), (Ciancio et al., 2016) and (Friesen et al., 2016). We also searched the literature for studies that evalu- ated the efficiency of computer systems in supporting wound treatment. Three nursing studies were found that assessed efficiency and other aspects of quality of systems aimed at end users: (Sperandio, 2008), (Tibes et al., 2015) and (Oliveira and Peres, 2015).

Cohen and Bard (Cohen and Bard, 2015) describe a mobile application developed at the Worcester Poly- technic Institute, called Sugar, to help people with diabetes manage their blood sugar level and the state of chronic foot ulcers. The app is available only for Android smartphones and communicates via wire- less internet to the patient's glucose meter in order to track blood sugar levels and weight. The app uses the device's camera to capture and analyze images of chronic foot injuries. It tracks the wound area and healing state and then reports the information in an easy format for patients. The app can be used only to analyze injuries in the foot region.

DigitalMediaLab developed WoundDesk (DigitalMedLab, 2019), a mobile solution for wound management, which, according to them, saves 60% of documentation time, medical errors and increased wound healing improvement. The application has wound evaluation features, automated analysis, semi-automatic and sterile wound measurement, and documents patient information. The app is available for both Android and IOs for free. The calculation of the area is semi-automatic, as you need to place a ruler next to the wound so that the processing algorithm can calculate a coarse estimation of the PU area. This can lead to risks of wound contamination.

In Friesen (Friesen et al., 2016), the development of the SmartWoundCare app is described, designed to document and evaluate chronic wounds through Android and iOS smartphones and tablets. The application uses the Braden scale to predict the risks of wounds, evaluates and stores all patient information on the device in a standalone mode, without the patient's registration function. In addition, the application does not analyze the area of the lesion and does not generate a report of the data collected from patients.

Ciancio et al. (Ciancio et al., 2016) describes the MOWA - Mobile Wound Analyzer app. The application performs the identification of the existing tissues in a wound from the capture of an image of the site. With this, it provides a list of care suggestions. Like WoundDesk, MOWA calculates the area of the lesion with the aid of a ruler, making the procedure vulnerable to contamination of the region and it can produce bad estimations. Because it is an app without new up- dates its interface is to be desired and is probably no longer compatible with some versions of Android and IOs systems.

In Oliveira (Oliveira and Peres, 2015), the study aims to evaluate the functional performance and technical quality of the Electronic Documentation System of the Nursing Process at the University Hospital of the University of São Paulo, called PROCEnf-USP. The evaluation was based on the Quality Model of the standard 25010 and the Evaluation Process de- fined in standard 25040 and used the following parameters: functional suitability, reliability, usability, performance efficiency, compatibility, security, maintainability and portability.

In Sperandio (Sperandio, 2008), the research sought to assess the functional performance and technical quality of the prototype software developed for nursing assistants. The software developed for mobile devices with integrated wireless network interface, al- lows nurses to access information and document data about patients at the bedside. Said author used the Evaluation Process Model provided in the ISO / 9126

standard, which deals with the external and internal quality of the software. This model uses six quality evaluation parameters, namely: functionality, reliability, usability, efficiency, maintainability and portability. However, in his study, the evaluation of the quality attributes of the prototype software was based on usability and efficiency.

In Tibes (Tibes et al., 2015), the UpCare application was evaluated by a committee of computer specialists and nursing specialists. The evaluation was based on aspects of functionality, reliability, usability, efficiency, maintainability and portability. For this, two questionnaires were developed, based on the study by (SPERANDIO, 2008), which evaluate these aspects.

Although it is possible to find studies that have evaluated the efficiency of in supporting the treatment of wounds, there is a lack in the literature regarding regarding works that address battery consumption and run time of image segmentation and classification algorithms in classification systems of wounds. The papers did not address wound segmentation and classification algorithms, and did not analyze consumption battery life of the proposed systems.

3 WoundArch ARCHITECTURE

The present system follows the client-server architecture shown in Figure 2, where the client uses its mobile device to capture and segment the image of the wound, while the server is responsible for the classification of the tissues and the computation of the tissues' areas.

In this work, we built on the work proposed by Godeiro et al. (Godeiro et al., 2018), which per- forms the segmentation and classification of chronic wounds. Figure 3 describes the steps performed for the execution of the segmentation and classification steps, which we will describe shortly.

3.1 Image Acquisition

At this stage, a specific protocol is defined for capturing the images by using the mobile device, in order to avoid the presence of noise as well as the presence of other parts of the human body that may interfere with the image preprocessing process. In addition, the

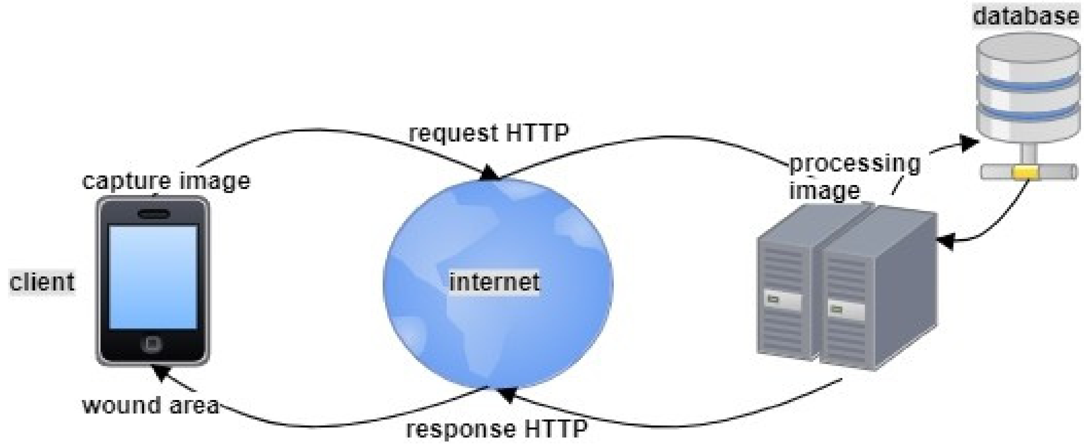

Figure 2: Client-server architecture.

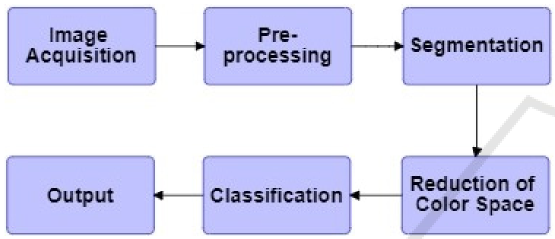

Figure 3: System flow chart.

following protocol aims to ensure equal lighting conditions for all photos taken. Godeiro (Godeiro, 2018) defined the following acquisition protocol:

1. Take the photo at a distance between 30cm and 40cm from the wound;
2. Take the photo with a white or blue background to avoid adding unwanted objects in the background (e.g. parts of the human body or other object other than the wound);
3. Take the photo without flash to avoid adding extra brightness to the image;
4. When taking the photo, place an object with a known size in the image, at the same depth of the wound, to retrieve the scale of the pixels;
5. When taking the photo, use white lighting to avoid variations in image colors;
6. When taking the photo, make sure that the entire wound is equally illuminated to avoid shadows in the image.

3.2 Preprocessing

With the photo of the wound acquired, the application performs a color conversion of the RGB image to the HSV color system. The HSV model is used when it is necessary to identify colors very similar to other colors (Cardani, 2001). Unlike the RGB color system, whose color determinants are all parameters (red, green and blue), in the HSV model the color determinant is the hue. In our tool, the H and S components are used to detect skin color and remove the parts of the image that do not contain skin or wound. Then, the result obtained is converted from the HSV to the RGB color system.

3.3 Segmentation

At this stage, the objective is to identify the region of interest of the image so that the algorithm can eliminate the regency where there is no presence of lessions on the skin. For this, the Watershed segmentation method (Meyer, 1992) is used in the application. This region-based segmentation method delivers results with closed and well-defined contours, which is great importance to the image segmentation process.

This is a semi-automatic process, that receives user markings on the smartphone screen as an in- put to the segmentation method. This process is also used so the user can isolate a wound for processing, in the cases where more than one wound is present in the same picture.

3.4 Spatial Color Reduction

In the last step on the client side, a color reduction of the image is performed. First, each RGB color component of each pixel is quantized using 6 bits by dividing its value by 4. With this reduction, the histogram size changes from 256^3 possible colors to 64^3 possible colors. After this, the image in the RGB format is converted to the CIELab color space because it was designed to approximate the human vision, as a perceptually uniform model, i.e., the distance between colors in this space are approximately proportional to the color distances perceived by humans. Then, the frequency of colors in the histogram is computed and those with at least 0.05% instances are stored in a list of representative colors. The colors of the image are analyzed and those that were not saved in the list, i.e., not labeled as representatives, will be mapped into the closest color based on the Euclidean distance in the CIELab space.

After this color space reduction, the image is ready for the classification step, that can be performed locally or remotely by a server through HTTP requests that manage and forward the image data so that it can be processed. The choice of the model used for processing, being processed completely on the client side, or divided between the client and server depends on smartphone capabilities such as processing power and available storage, as well as network bandwidth and also security issues related to the available wireless networks.

3.5 Classification

Upon receiving the image, the server is responsible for classifying the tissues present in the wound as Necrosis, Granulation, or Slough. For this, a clustering is carried out by computing the Earth Mover's Distance (EMD) (Rubner et al., 2000). This distance measures the difference between signatures that are compact distribution representations by comparing two histograms and verifying how different these histograms are.

In order to do that, a set of 30 wound images was used to serve as a training base. During the training phase, we used patches 11 × 11, a size determined empirically (Godeiro et al., 2018), and used the EMD to retain only patches which were at a reasonable distance from the other retained patches. We also use an heuristic to reduce the number of patches per class that are used for comparisons in the classification, by keeping only the patches which have larger sum of distances from the other patches of the class. By doing this, we select only the more external elements of the cluster representing a class, i.e., the patches the define the external borders of the clusters.

Each patch of the analyzed image is compared by EMD with the entire set of patches retained in the training step. The tissue label associated with a pixel is defined by the smaller distance, computed using the EMD, between the patch centered at it and the training set patches.

4 EXPERIMENTS

All the experiments performed here were developed on a notebook equipped with an Intel Core i5 Processor (6th Generation) Model 6200U with 2 cores running at 2.3GHz, with 3MB of cache, 12GB DDR3L 1600 MHz RAM and running Linux Mint 19.3.

For the development of the server, the PHP language Version 7.2 was used, along with the web text editor PHPStorm 2019.3.4. The Laravel Framework for Web Artisans 6.0 was used in conjunction with the dependency manager Composer 1.10.1. For the computer vision stage, the OpenCV 4.1 library with C++ was used. For the development and emulation of the client, we used the Kotlin Language 1.3. The client used to perform the tests was the Redmi Note 8 Smartphone equipped with a Qualcomm SDM665 Snapdragon 665, an Octa-core (4 ×2.0 GHz Kryo 260 Gold & 4x 1.8 GHz Kryo 260 Silver) CPU, an Adreno 610 GPU, and 64GB of storage and 4GB RAM. This smartphone has a Quadruple Camera: 48 MP, f/1.8, (wide), 1/2", 0.8μm, PDAF + 8 MP, f/2.2, 13mm (ultrawide), 1/4", 1.12μm + 2 MP, f/2.4, 1/5", 1.75μm (dedicated macro camera) + 2 MP, f/2.4, 1/5", 1.75μm, depth sensor; 6.3 inches; with a maximum resolution of 1080 × 2340 pixels.

In this section, the prototype of the application is described (see Figure 4). The application interface is very lean and objective so that the nurse can ob- tain the wound information with a few touches on the screen. When opening the app, the nurse attaches the image of the wound, either by a photo captured at that moment or by an image from the gallery of the smartphone. The patient's name is then filled in and then the image is uploaded to the server or processed locally.

5 RESULTS AND DISCUSSION

For the purpose of validation of the client-server system, a base with 20 images of wounds was used. Table 1 presents the results obtained by the system divided into two scenarios: segmentation and classification in the client architecture; and segmentation on the client with classification of the wound on the server. In order to verify the efficiency between client and client-server, the execution times measured in sec- onds were compared. Each image was executed five times for each scenario. The Segmentation, Classification, and Total columns show the average times and standard deviation obtained. Even though the images are ordered by their total number of pixels, we can see that the second smallest image, 650 × 375, has the third highest execution average, 9.718 seconds, a circumstance that is related to the size of the wound area being analyzed.

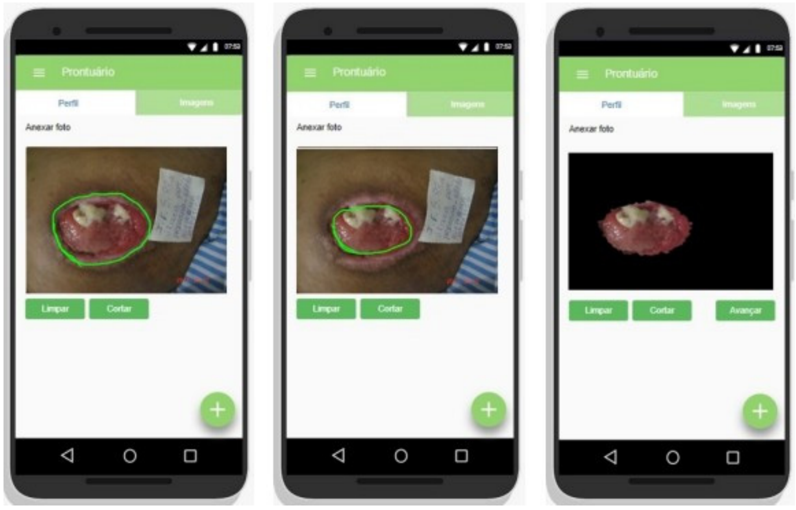

Figure 4: Example of the mobile application screen: processing seen on the client's App.

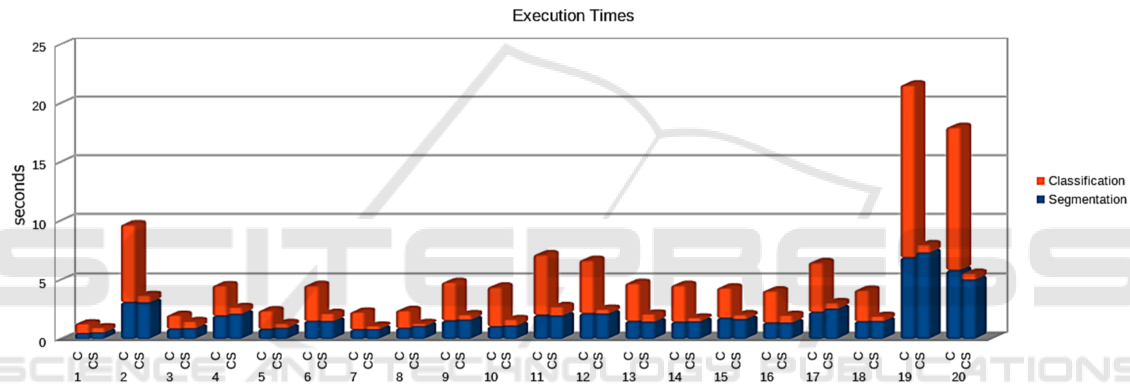

Figure 5: Execution times required for the segmentation (blue) and classification (red) tasks. The bars labelled C correspond to the execution times when both tasks were performed on the client side, while the label CS indicates that the classification task was performed on the server side.

In the client-only application, when analyzing the results of segmentation and classification, we can see that the classification time is roughly twice as long as the segmentation time. In classification, the vast majority of the results were below 10 seconds, only images 19 and 20 were classified on 21.584 and 17.990 seconds, respectively.

In the client-server application, due to the segmentation continuing to be performed on the client, the values showed little variations in relation to the exe- cution time of the client application, that can be ex- plained by different computational loads being exe- cuted on the smartphone. In the classification column, Images 19 and 20 achieved the largest time reduction compared to the client application, from 14.69 sec- onds to 0.70 and 12.18 to 0.55, respectively. Actually, all classifications in the server were performed in un- der a second, including the transmission time of the files in both directions.

The graph in Figure 5 shows the execution times for the two options of the proposed architecture, where the blue bars represent the segmentation time and the red bars represent the classification times. Analyzing the columns, it can be noted that the longest execution time was the one for Image 19 performed in the client application, with more than 21 seconds, while it took 8.01 seconds for the client-server architecture, followed by Image 20, with 17.99 seconds for the client application, and 5.57 seconds for the client- server.

A similar pattern can be observed for Images 2, 11, 12 and 17. The speedups obtained by the usage of the client-server architecture in relation to the client-only varied from 1.35 to 3.23 times. Therefore, it can be easily observed on Table 1 and Figure 5 that the Client-Server architecture proposed is advantageous when compared to a standalone, or as it is called here, client-only architecture for solving this problem.

Table 1: Execution times (in seconds) for the segmentation and classification. The Classification* times reported for the Client-Server system includes the transmission times of the segmented image to the server and the classification map back to the client.

Image		Client			Client-Server		
N	Size	Segmentation	Classification	Total	Segmentation	Classification*	Total
1	500 × 435	0.45 ± 0.84	0.84 ± 0.21	1.29 ± 0.20	0.51 ± 0.04	0.45 ± 0.44	0.96 ± 0.46
2	65 × 375	3.10 ± 0.22	6.62 ± 0.03	9.72 ± 0.21	3.07 ± 0.19	0.62 ± 0.30	3.69 ± 0.35
3	800 × 500	0.84 ± 1.17	1.17 ± 0.09	2.01 ± 0.19	0.88 ± 0.06	0.60 ± 0.52	1.48 ± 0.58
4	900 × 700	1.95 ± 0.34	2.58 ± 0.32	4.53 ± 0.66	2.10 ± 0.26	0.57 ± 0.44	2.67 ± 0.44
5	1000 × 667	0.82 ± 0.09	1.58 ± 0.07	2.40 ± 0.15	0.91 ± 0.12	0.40 ± 0.35	1.31 ± 0.40
6	1000 × 669	1.50 ± 0.18	3.05 ± 0.04	4.54 ± 0.21	1.47 ± 0.04	0.69 ± 0.40	2.16 ± 0.43
7	1024 × 703	0.78 ± 0.04	1.50 ± 0.06	2.28 ± 0.09	0.80 ± 0.05	0.29 ± 0.09	1.10 ± 0.14
8	1024 × 768	0.89 ± 0.03	1.52 ± 0.05	2.41 ± 0.06	1.06 ± 0.10	0.24 ± 0.06	1.30 ± 0.14
9	1102 × 575	1.54 ± 0.18	3.27 ± 0.40	4.81 ± 0.57	1.61 ± 0.02	0.45 ± 0.27	2.05 ± 0.28
10	1111 × 640	1.03 ± 0.10	3.38 ± 0.23	4.41 ± 0.30	1.10 ± 0.07	0.54 ± 0.39	1.64 ± 0.39
11	999 × 1228	2.00 ± 0.23	5.15 ± 0.11	7.16 ± 0.33	1.94 ± 0.07	0.80 ± 0.55	2.74 ± 0.54
12	1280 × 960	2.15 ± 0.28	4.54 ± 0.21	6.69 ± 0.34	2.12 ± 0.10	0.40 ± 0.07	2.52 ± 0.07
13	1333 × 885	1.49 ± 0.05	3.24 ± 0.05	4.73 ± 0.09	1.43 ± 0.09	0.69 ± 0.46	2.13 ± 0.49
14	1400 × 931	1.42 ± 0.03	3.13 ± 0.03	4.55 ± 0.09	1.47 ± 0.08	0.32 ± 0.11	1.79 ± 0.15
15	1460 × 980	1.75 ± 0.13	2.59 ± 0.02	4.34 ± 0.14	1.64 ± 0.05	0.40 ± 0.23	2.04 ± 0.26
16	1600 × 800	1.35 ± 0.08	2.73 ± 0.01	4.08 ± 0.08	1.35 ± 0.15	0.65 ± 0.40	2.00 ± 0.48
17	1637 × 1255	2.26 ± 0.13	4.23 ± 0.03	6.50 ± 0.16	2.55 ± 0.14	0.53 ± 0.40	3.07 ± 0.40
18	1850 × 870	1.46 ± 0.02	2.69 ± 0.04	4.15 ± 0.05	1.48 ± 0.06	0.44 ± 0.42	1.92 ± 0.44
19	1505 × 1852	6.90 ± 0.50	14.69 ± 0.29	21.58 ± 0.23	7.31 ± 0.28	0.70 ± 0.13	8.01 ± 0.22
20	2048 × 1536	5.81 ± 0.45	12.18 ± 0.37	17.99 ± 0.66	5.01 ± 0.09	0.55 ± 0.15	5.57 ± 0.21

Moreover, the usage of the proposed client-server architecture allows the system to keep synchronized by saving the processed images and generating and storing reports about the wound treatment evolution. One can also point out to the fact that the computer used as a server is far from being a high end PC, and so, the usage of a more powerful computer can offer much higher throughputs.

6 CONCLUSIONS

Mobile apps have proven to be important tools with great potential for benefits for health activities. In this work, we propose a mobile application for fol- lowing the treatment of chronic wounds. This task is achieved by performed the segmentation and classification of chronic wound tissues and keeping track of the treatment evolution. The main objective is to pro- vide health professionals with a tool capable of accu-rately classify the areas of these lesions occupied by slough, granulation and necrosis tissues.

In order to validate the work, we performed experiments with the segmentation and classification tasks organized into a client-only and a client-server architectures. The results show the advantage of the client-server architecture over the client-only, with speedups of up to 3.2 times being achieved. The client-server architecture also saves power and space on client units, thus, increasing the up time of the smartphones used as clients as well as decreasing the storage burden on them. This allows for the usage of lower end smartphone as clients.

The work developed here is part of a proposed mobile application for wound care. Future work include incorporating a three-dimensional reconstruction module in order to make the area measurements more accurate and provide information about the wounds' depths. We also plan to develop a follow-up module that will store the treatment progress and a diagnostic module that will suggest potential treatments based on historic data. Finally, it is necessary to improve the graphical interface to improve its usability.

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