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ORIGINAL ARTICLE

IMAGE PROCESSING IN MOBILE DEVICES TO CLASSIFY PRESSURE INJURIES PROCESSAMENTO DE IMAGENS EM DISPOSITIVOS MÓVEIS PARA CLASSIFICAR LESÕES POR PRESSÃO PROCESAMIENTO DE IMÁGENES EN DISPOSITIVOS MÓVILES PARA CLASIFICAR LESIONES POR PRESIÓN

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ABSTRACT

Objective: to develop an algorithm that helps classifying pressure injuries through image processing on mobile devices. **Method:** there are four main stages of development of the algorithm: building an image database; extracting images of the features; definition of a function that calculates the similarity between images; and recovery of the reference image most similar to the new image. Finally, a panel formed by nurses tested the accuracy of the system. **Results:** in the developed system, the user must upload a photo of the injury; the system will process that image, and, based on the processing algorithm implemented in the application, will make a suggestion of the likely stage of the injury. **Conclusion:** in the tests to verify the accuracy of the classifications through the algorithm, there were 100% of accuracy. Despite the limitations of the algorithm, the result of this research is encouraging and future studies should expand it. **Descriptors:** Nursing Informatics; Medical Informatics; Patient Safety; Pressure Ulcer.

RESUMO

Objetivo: desenvolver um algoritmo que auxilia na classificação das lesões por pressão por meio de processamento de imagens em dispositivos móveis. **Método:** podem-se destacar quatro etapas do desenvolvimento do algoritmo: construção de um banco de imagens; extração de características das imagens; definição de uma função que calcule a similaridade entre imagens; e recuperação da imagem de referência mais similar à nova imagem. Por fim, uma banca de juízes formada por enfermeiros testaram a acurácia do sistema. **Resultados:** no sistema desenvolvido, o usuário deve carregar uma foto da lesão, então o sistema fará o processamento dessa imagem e, baseado no algoritmo de processamento implementado no aplicativo, fará uma sugestão do provável estágio da lesão. **Conclusão:** nos testes realizados para verificar a acurácia das classificações por meio do algoritmo, obteve-se 100% de acerto. Mesmo considerando as limitações do algoritmo, o resultado desta pesquisa é encorajador e deve ser expandido em trabalho futuro. **Descritores:** Informática em Enfermagem; Informática Médica; Segurança do Paciente; Úlcera por Pressão.

RESUMEN

Objetivo: desarrollar un algoritmo que ayuda en la clasificación de las lesiones por presión a través de procesamiento de imágenes en dispositivos móviles. **Método:** se pueden destacar cuatro etapas del desarrollo del algoritmo: la construcción de una base de datos de imágenes; extracción de características de las imágenes; definición de una función que calcula la similitud entre las imágenes; y la recuperación de la imagen de referencia más similar a la nueva imagen. Por último, una banca de jueces formada por enfermeras puso a prueba la precisión del sistema. **Resultados:** en el sistema desarrollado, el usuario debe subir una foto de la lesión, entonces el sistema procesará esta imagen, basado en el algoritmo de procesamiento implementado en la aplicación, hacer una sugerencia probable escenario de la lesión. **Conclusión:** en las pruebas para verificar la exactitud de las clasificaciones a través del algoritmo, se obtiene una precisión del 100%. A pesar de las limitaciones del algoritmo, el resultado de esta investigación es alentador y debería ampliarse en trabajos futuros. **Descriptor:** Informática Aplicada a la Enfermería; Informática Médica; Seguridad del Paciente; Úlcera por Presión.

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INTRODUCTION

The National Pressure Ulcer Advisory Panel (NPUAP), in 2016, released the new definition of Pressure Ulcers (PU), in which the new name for that type of injury became Pressure Injuries (PI). The PI characterize by damage to the integrity of the skin and/or underlying tissue, usually over bony prominence, with or without pain. The injury may have intact skin or an open ulcer. There is also a further classification of PI in stages according to the degree of impairment of the injured tissue.¹

For proper treatment of PI, it is essential to identify the tissue and classify the injury correctly. Furthermore, a study, which aimed to determine the aspects considered by nurses in the evaluation of wounds and possible complicating factors in that process, found that, among some of the causes that hinder the evaluation of those wounds, are the lack of protocol and the lack of specific experience and training of professionals.²

Assessing, identifying tissues and classifying PI based only on look and manual documentation of the health professional may become subjective and inaccurate. Studies show discrepancies in identifying scar tissue or the size of the injury, and up to 30% of differences among health professionals in relation to diagnosis.³

A study conducted in order to train nursing professionals on the prevention and treatment of PI performed tests before and after the training. When working with questions concerning the classification of PI, nurses reached a low percentage of correct answers on questions in the pre-qualification phase and even in the post-training phase, they reached only 73.13% of correct answers. Even with improvement in the percentage of correct answers, that index is still below the 75% parameter, a percentage that define the participants in the study know the domain. One can understand that, in that study, knowledge of issues related to the classification of PI among professionals, even after training, still needs to be addressed with a view to assist nurses and other health professionals about evaluation of PI.⁴

In this sense, computer technologies can be an important aid in practice and in direct patient care, in the development of researches, and in the teaching and learning process, since combining nursing education to technologies innovate and, at the same time, streamlines the way teaching and work⁵⁻⁶. Furthermore, another study found the increased use of computer technology by nurses and indicated that the majority of

those professionals use the computational resources for the development of their work.⁷

In this scope, image processing may be an ally to assist classifying PI. Image processing is a Computer Science area focused on developing algorithms for data processing in which the input and/or output involve digital images.⁸⁻⁹

In order to assist nurses in the classification of PI, this study aims to develop an algorithm that helps classifying pressure injuries through image processing on mobile devices.

METHOD

Study developed from an applied research that aims to develop an Application (APP) for mobile devices that has an algorithm that helps in the automation of the PI classification through digital image processing.

Applied research refers to the generation of knowledge for the development of new products or improving existing ones, providing the need for a place for solving a specific problem, that is, it uses the knowledge generated by basic research to practical application with products, given a pre-established demand.¹⁰

This study was approved by the Ethics Committee in Research in Human Beings of the Federal University of São Carlos/UFSCar, under opinion No. 393,976, meeting the requirements of Resolution 466/12.¹¹

All subjects in the study were informed about the study objectives, highlighting the availability to clarify any doubts. Participation in the survey was carried out by signing the Informed Consent Form (ICF), which ensures confidentiality and anonymity, withdrawal at any stage of the research, at no cost, and the authorization for the dissemination of results.

◆ Development method

The purpose of using the image-processing algorithm in this study is to, providing to the system a new image of PI, automatically identify the most similar image in a reference image bank and, thereby, estimate the PI stage of the new image subjected to algorithm.

An image, in turn, can be defined as a two-dimensional function, $f(x, y)$, where x and y are coordinates on a spatial plane and the value of f , at any pair of coordinates (x, y) , is called color intensity or image gray level at that point. When x , y and f values are all finite, that is, discrete values, the image may be called a digital image. Thus, a finite number of elements, with their location and value, compose each image. Those elements are widely known as pixels.⁸⁻⁹

There are various systems for defining the color intensity or gray level value (value of function f). A system widely used for the representation of digital images is the RGB (English acronym for Red, Green and Blue). That system forms the various colors of the pixel defining the intensity of each of the three components (red, green and blue). When the three components have maximum intensity, the color to be displayed to the pixel is white. On the other hand, black is shown when the intensity is zero in all components.⁸⁻⁹

The combination of pixels, each with its position and intensity of color, form digital images.

In order to achieve the general objective of this study, which is the development of an algorithm that helps in the automation of the PI classification through digital image processing in mobile devices, four steps can be highlighted:

I. Construction of a reference bank with PI images.

II. Extraction of the images characteristics.

III. Definition of a function that calculates the similarity between the images.

IV. Recovery of the reference image most similar to the new image provided to the algorithm.

Next, there will be the description of each stage.

Stage I - Construction of a reference bank with PI images: in the first stage, one organized a bank with eight images, two for each stage of the injury (I to IV stages were considered). The images and their proper use rights were acquired in the NPUAP site. NPUAP previously studies and classified the images selected to be the reference bank according to their stage.

Thus, in addition to the images, the stage of each injury is also stored in the computer system. Next, there was a division of that bank into two sets: one for reference (training set) and another for testing the accuracy of the developed algorithm (test set). Each of the banks (training and testing) consists of four images, one image for each stage of the injury.

Stage II - extraction of the image characteristics: in this step, the features that summarize each image are extracted, in order to calculate the similarity between them and, thereby, recover the most similar image(s).

There are several techniques available in the literature on image-processing area for that purpose. In this study, the technique used to characterize each image was the "color histogram", due to its simplicity⁸. Simplicity is an important feature, since the purpose of this work is an early reference on the use of image-processing techniques to classify PI in Brazil. Furthermore, one expects health researchers to be able to reproduce more easily, in other studies, the method here presented.

In order to better understand the technique, a histogram is usually a graphical representation to indicate the frequency distribution of a set of values. In the image-processing context, that technique consists in analyzing the image, pixel to pixel, to count the frequency with which each color intensity is present in the image⁸. In the case of the extraction of PI images characteristics, an important advantage of that technique it is that the histogram is not sensitive to the rotation or position of the PI in the image.

Figure 1 illustrates the construction of the color histogram of the studied PI images¹². One can see that those histograms are normalized in values ranging between zero and one. The normalization is important so that all analyzed images exhibit the same range of values, besides preventing the overlap of one of the image channels (red, green or blue) in relation to the other. The left side of Figure 1 displays the histogram of each color channel (RGB) separately, given a PI image. On the right, three concatenated histograms are displayed, forming a single image feature vector.

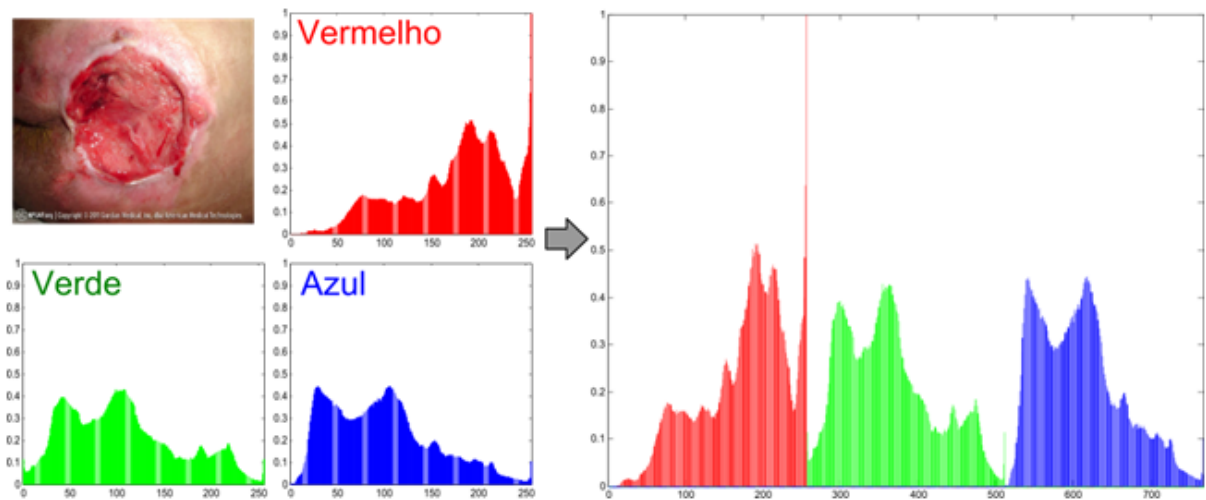


Figure 1. Illustration of the process of images characterization using color histogram.

Stage III - Definition of a function that calculates the similarity between the images: the third step defines the metric that will calculate the similarity between two images represented by their feature vectors *h1* and *h2*.

For this, various metrics may be used. This research elected the Euclidean distance (ED),

as it is a simple and widely used metric that requires no parameters and provides competitive results with other more sophisticated measures¹³. The following equation defines the ED:

$$d(h1,h2) = d(h2,h1) = \sqrt{\sum_{i=1}^n (h1_i - h2_i)^2}$$

where *h1* and *h2* are the normalized color histogram vectors, which, in the case of this research, represent the images to be compared and *n* is the number of dimensions of the vectors (color intensity). The ED is responsible for measuring the similarity between two feature vectors considering a

linear alignment between the vectors. Figure 2 shows an intuition of the comparison performed by the ED, given two vectors. At the end, the Euclidean distance returns a single value that represents the sum of all squared differences.

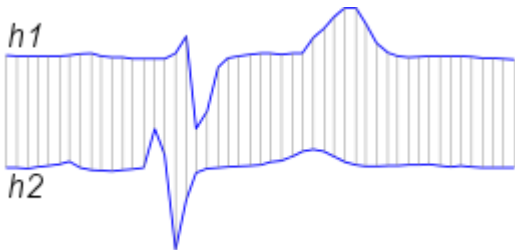


Figure 2. Linear alignment conducted by ED when comparing two vectors *h1* and *h2*.

Stage IV - Recovery of the reference image most similar to the new image provided to the algorithm: the fourth and last stage defines the algorithm sued to recover the image(s) most similar to the new image processed by the APP. In order to do so, one used the *k*-NN algorithm (from English, *k*-Nearest Neighbors).¹⁴

When processing an image, that algorithm aims to recover the most similar *k* examples (images) within the bank of reference examples. The recovery is in accordance with the values of similarity between the images obtained from the Euclidean distance. As there is interest in recovering only the most

similar image of the reference bank, the algorithm parameter is defined as *k=1*.

Thus, when recovering the most similar reference image, one simply uses the stage previously known and attributed to the image as the estimate of stage for the new image.

In addition to the four steps for processing the studied images, there was the assessment of software quality. A panel of nurses performed the evaluation, which aimed to identify the rate of right PI classification made by the system. For this, the nurses had access to the algorithm available through an APP on a mobile device. In the test, the nurses submitted to the algorithm previously classified PI images, the result provided

automatically by the system was compared to the stage previously known by judges.

RESULTS

There was an implementation of the image-processing algorithm in an APP for mobile devices so that nurses could test/use it¹². For developing the APP, development tools for the Android platform were used.

In the developed system, the user must load an image of the gallery or capture a

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photo of the injury directly on the mobile device. After selecting the photo of the injury for analysis, the system will process this image and, based on the processing algorithm implemented in the APP, will make a suggestion of the likely stage of the PI. The user can choose if the system recommendation based on the image is appropriate (confirm) or not (change) (Figures 3 and 4).

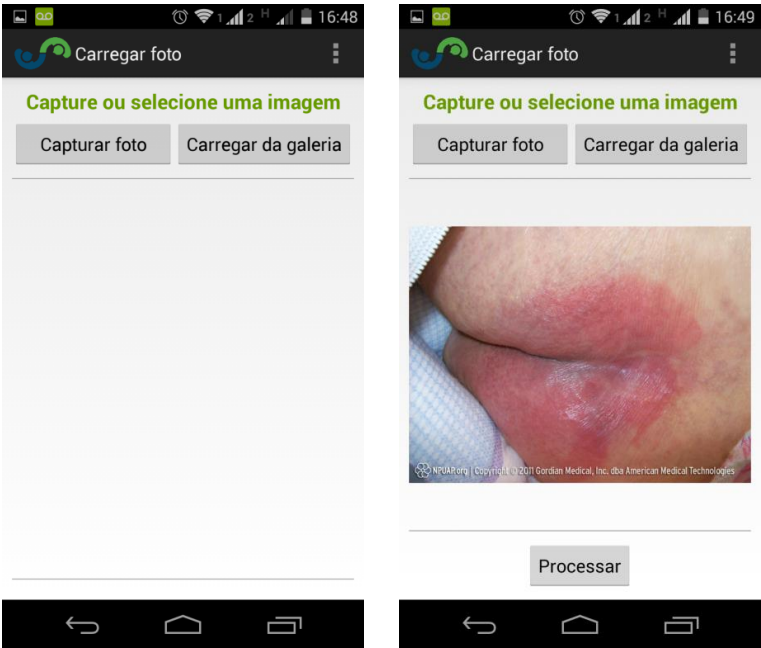


Figure 3. Selection of the image for the system analysis.

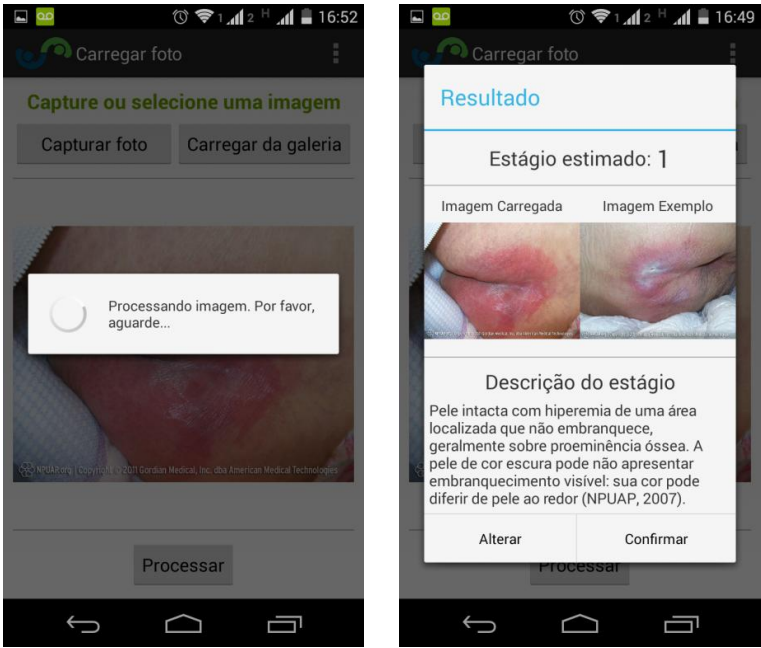


Figure 4. Processing of the studied image and PI classification.

As previously mentioned, two sets of images were used to develop and test the image-processing algorithm. The set called "training" with four reference images, one for each stage of the PI, is the images bank stored in the APP. Thus, the remaining images formed the "test" set.

Nurses used the "test" set to assess the accuracy of the information provided by the algorithm. The evaluation aimed to verify the feasibility of automatically identifying the

stage of the PI and the constructed model showed 100% accuracy in the tests.

As there is no guarantee that the image-processing method embedded in the APP always provides perfect suggestions of the PI stage, the APP has a second option to support the user in the PI classification. In this approach, the user can manually enter the stage he/she considers relevant and the APP provides decision support for the user by providing the definitions of each stage

according to NPUAP and illustrative images of each stage of the PI.¹

For manually inserting the PI stage, the user must click on the button “Change”

(Figure 4) and, then, the APP will provide the description of each stage, as seen in Figure 5.

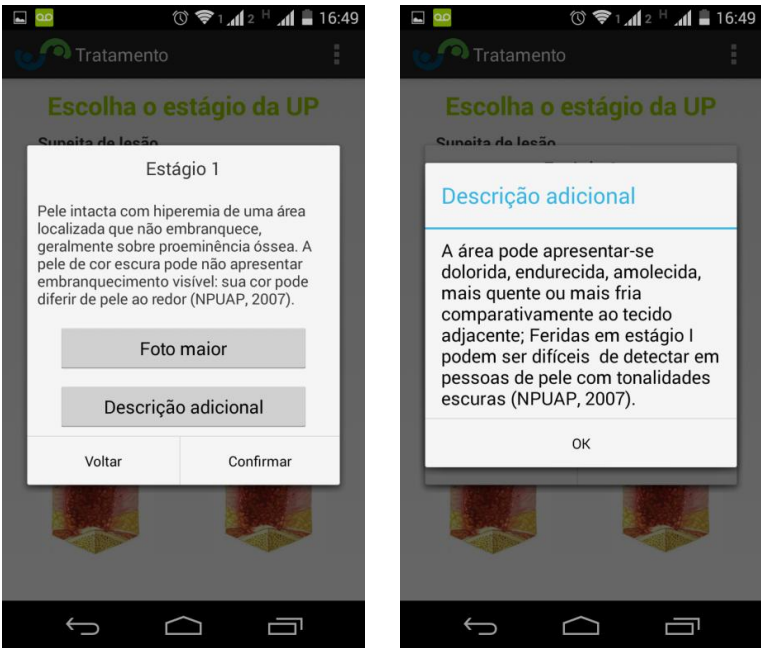


Figure 5. Decision support based on information.

The last step of the “PI Classification” is confirmation. After checking the suggestions, definitions and/or examples in the APP, the user can conclude the actual PI stage and confirms in the system by clicking the “Confirm” button (Figure 5).

DISCUSSION

The use of computers in health care is increasingly expanding, because this type of support enables professionals to achieve greater precision and agility in their work. Regarding nursing in Brazil, the adoption of technological resources is a growing fact since the late 60's and have been used to support decision-making, the orientation of patient education and training of professionals and students, in the documentation of the nursing process, in systems of hospital information and electronic registration in health.¹⁵

This research aimed to develop an algorithm to assist in decision-making against the classification of PI. The implementation of the developed algorithm occurred on an APP for mobile device, as mobile devices, tablets and smartphones have become popular, representing, thus, a tool of easy access and manipulation by nursing professionals.

A panel formed by nurses tested the accuracy of the developed system. In tests conducted in this study, the algorithm showed 100% accuracy, suggesting that the system developed in this research is promising.

It is noteworthy that, in the used method, the greater the number of images in the training set, the better will be the accuracy of the image-processing algorithm to predict the

stage of the PI. Similarly, the greater the number of images used in all tests, the better the evaluation of the algorithm to predict accurately the injury stage for a new image.

Thus, although obtaining 100% of accuracy for the tested images, there should be an expansion of that set of images to hundreds of pictures, as normally performed in studies evaluating the accuracy of image-classification algorithms.^{8-9,16}

Moreover, it is noteworthy that the assessment used photographs of a single anatomical area, as recommended by Baumgarten and colleagues¹⁷. Thus, the precision result obtained in this study cannot be extrapolated to other anatomical areas without specific assessments for those cases.

Therefore, a greater number of images is essential to expand this research. For this, some aspects should be considered in the acquisition of those images to allow the use of photography in the PI classification, such as: standardization of the anatomical areas to be photographed, training of health professionals to properly acquire those images and use of devices with similar specifications.¹⁷

Even considering the limitations previously mentioned, the result of this study is encouraging and future studies should expand it both to evaluate other anatomical areas as to the analysis of a larger number of images. In addition, the APP provides alternative ways to confirm the suggestion provided by the image-processing algorithm, since the user can evaluate the response provided by the APP, agreeing, or not, with the classification.

The presentation of concepts about the PI stages can help standardize its classification by professionals through the dissemination of concepts worldwide validated by NPUAP. In addition, one believes that the APP will have the educational potential to even adjust possible concepts wrongly understood by health professionals.

The objective of the APP is to assist in decision-making and do not provide a definitive answer. In the future, for a possible improvement of the APP responses, there will be an evaluation of a larger number of images and other image-processing methods that consider the diameter and depth of the identified injuries.

In this scope, one may highlight the importance of developing multidisciplinary work, which enables the development of technologies for health area, integrating nursing knowledge and computing. This type of development is very important for the health, since the use of computer technology has been widely spread and generated significant improvements in different areas.¹⁸

CONCLUSION

As a result of this research, one obtained an application for the Android platform that has an image-processing algorithm to classify PI automatically and provides information about concepts that help in decision-making.

For developing the module to process images, the color histogram method was used. In tests to verify the accuracy of classification through the image-processing algorithm, there were 100% of accuracy in predicting the PI stages. Nevertheless, a larger number of images, in both the training set as the test set, will provide a more accurate assessment to the used method and may also increase the accuracy of the image-processing algorithm to predict the stage of the injury for a new image. Therefore, future studies should build a bank of larger images in order to improve the processing algorithm and its evaluation. Additionally, one intends to study more sophisticated image-processing methods, which consider the diameter and depth of the assessed injury, besides characterizing the skin.

Even considering the limitations of the APP, the result of this research is encouraging and future studies should expand it.

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