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Medical Imaging Fusion: A Teaching-Learning Simulation Environment

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Abstract—The use of computational tools has become essential in the context of interactive learning, especially in engineering education. In the medical industry, teaching medical image processing techniques is a crucial part of training biomedical engineers, as it has integrated applications with health care facilities and hospitals. The aim of this article is to present a teaching-learning simulation tool, developed in MATLAB using Graphical User Interface, for medical image fusion that explores different image fusion methodologies and processes in combination with image pre-processing techniques. The application uses different algorithms and medical fusion techniques in real time, allowing to view original images and fusion images, compare processed and original images, adjust parameters and save images. The tool proposed in an innovative teaching and learning environment, consists of a dynamic and motivating teaching simulation for biomedical engineering students to acquire knowledge about medical image fusion techniques, necessary skills for the training of biomedical engineers. In conclusion, the developed simulation tool provides a real-time visualization of the original and fusion images and the possibility to test, evaluate and progress the student's knowledge about the fusion of medical images. It also facilitates the exploration of medical imaging applications, specifically image fusion, which is critical in the medical industry. Teachers and students can make adjustments and/or create new functions, making the simulation environment adaptable to new techniques and methodologies.

Keywords—Image fusion, image processing, teaching-learning simulation tool, biomedical engineering education.

I. Introduction

COMPUTATIONAL tools have become an almost permanent element and must be present in new interactive learning schemes, practically for all educational topics in engineering education [1]. Since the beginning of the 1990s, tools with a graphical interface have been developed for teaching image processing in the area of health and engineering [2] - [5]. More recently, studies on the development of these tools open new perspectives, exploring more enriching learning scenarios where students and teachers engage in real practices. Learning spaces for the development of new experiences in collaborative environments, so that students transform everyday life scenarios into experiential learning spaces [6] as the case of a study of third-year Biomedical Engineering students on complementary activities of learning in "Second Life" focused on learning oral and written skills of scientific content [7] or the applied case study in Biomedical Engineering for the development of a learning module for segmentation of digital images of Computed Tomography and detection of their specific anatomical features [8].

The teaching of medical image processing techniques and tools is an important part of the training of a Biomedical Engineer, since this process is integrated in health units, hospitals and the medical industry. The analysis of different types of medical images has become, in the last century, an important tool for medical diagnosis. Sometimes, to diagnose a specific pathology, an image showing metabolic activity is complemented by another image showing the anatomical structure of the same region. It is in this sense that the fusion of images (anatomical or functional) has great technological potential, as it helps in the diagnosis, in the decision of surgeries and in the development of certain pathologies. For example, the combination of data obtained from different exams in a single image makes it possible to specify the extent of anatomical impairment (for example, with a Magnetic Resonance Image (MRI)) and physiological (for example, with an infrared image), accurately diagnosing the location of changes in blood level and their physiological effect. It is, therefore, a critical area in the training of biomedical engineers.

This work arises from observation in the orientation of the final projects of the Degree in Biomedical Engineering, where most of the students end up spending a lot of time trying to generate efficient programming routines than learning the concepts and techniques of medical image processing, since the majority of these students are not programmers. Hence the objective of presenting a teaching-learning tool developed in Matlab using the Graphical User Interface (GUI), for the fusion of medical images using some algorithms and image processing techniques. The image fusion modeling can be obtained by different algorithms and using some preprocessing techniques implemented to "improve" the original images through the adequate definition of some parameters.

II. Medical Image Fusion Methods

In image fusion, there are two major steps: first, image registration and secondly, the fusion of the relevant characteristics of the registered images. When recording images, a method is needed to correct the spatial misalignment resulting from changes in scales and/or rotations, and pre-processing techniques to improve the quality of the image. In image fusion there are currently several methods, with different limitations. In more classic methods, the images have a weak correlation, either due to the time difference between the acquisition of the two images, or due to the spectral

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differences between them. In the most recent fusion methods, the distortion of the spectral information is much smaller, or even non-existent, however distortions may occur at the spatial level [11].

- Morphological methods: The concept of morphology operators is widely used in image processing as it allows segmenting and identifying regions of interest in digital images. In medical images, morphological operators perform a sequence of mathematical operations that allow the identification and detection of specific features in image fission, mainly MRI and Computed Tomography (CT) [9].
- Knowledge-based method: The domain of medical knowledge is necessary to restrict the segmentation of the region of interest. In this case, great reliance is placed on the physician's experience and the images are compared with known standards of human vision. However, it has the limitation of human appreciation, subject to errors, mainly in images with noise and variations in intensity. [9].
- Methods based on Wavelets functions: The original images usually have different frequencies in time and space, and can be transformed with Wavelet functions so that it is possible to analyze them on an identical time scale and frequency, improving the quality of their fusion. There are two types of Wavelet Transforms: Continuous and Discrete.

III. Methodology

During the 2021-2022 school year, a simulation tool was developed that intends to explore different image fusion processes and methodologies in combination with image pre-processing techniques and methods. The tool was implemented in MATLAB [10] because it is freely available throughout the entire campus of the Coimbra Institute of Engineering and because of the possibility of using several image processing toolboxes. This tool, in addition to being widely used in environment academics, allows the creation of a Graphic User Interface (GUI), regardless of the implemented routines. The structure of the developed application is presented in Fig. 1 and is divided into two stages. Step 1 (on the left) is responsible for all the registration of the two images A and B, that is, the loading of the original images (A and B), their pre-processing, where techniques and algorithms are applied to correct the brightness, noise removal, image filtering, histogram equalization, etc. to improve image quality (A1 and B1). And finally the adjustment of the images leaving them aligned with each other, through scales, rotations, etc. (A2 and B2). In step 2 (on the right), the fusion is applied to images A2 and B2. The three defined methods are: ”Addition”, ”Fusion” and ”Fusion using Wavelets”.

Although there are several image fusion methods, in this work only three of these methods will be used, namely the "Addition" method, the "Fusion" method and the "Fusion using Wavelets" method. The first method adds to each element in the matrix image A2 the corresponding element of the matrix image B2 and returns the resulting matrix image (C1), sum of these elements. The "Fusion" method, on the other hand, initially converts color images into A2 and B2 grayscale images by matching the color of a color pixel to a grayscale intensity. In this scale, the darkest pixel is represented by 0 and the lightest by 1. The method allows choosing the way of scaling the image through a definition parameter. This means that both images can be scaled separately or together. Finally, each grayscale image is placed in a different color channel, and the resulting image is a composite image of these images (C2). The third method uses the principle of fusing images (A2 and B2) with procedures similar to the previous method but using Wavelets to fusing the resulting image (C3).

The application developed and represented in Fig. 2 allows choosing two original images of different types of medical exams A and B (upper button in the left menu) and viewing them in the application (top right). According to the chosen fusion algorithm, the final image of the fusion of the two initial images is visualized (bottom right). It is possible to obtain the fusion of the initial images using different algorithms or for the same algorithm to choose different initial images. The tool also allows, the visualization of the original images and the fusion image in real time.

It is also possible to change the brightness of the images resulting from the first two methods using the bar located in the lower left corner, or even define the type of fusion (”Maximum”, ”Minimum”, ”Medium” or ”Random”), to be chosen to apply the Wavelet fusion, using the list in the lower right corner.

Another possibility, implemented in this application, is the possibility of monitoring over time images of different types or of the same type obtained at different times, which after being saved in different formats, can later be compared using different fusion techniques.

IV. Results and Analysis

Several tests were carried out on the application using medical images in an open format on the internet. A first simulation consisted of merging two brain images (Fig. 2). The first image loaded in the application, image A is a Positron Emission Tomography (PET) type with contrast (left upper) and image B is a Magnetic Resonance Image (MRI) type in grayscale (right upper). The result obtained by fusion these two images using the three different methods can be found below. The C1 image obtained as a result of the first fusion method is an image with greater luminosity as it is the sum of the colors of 2 images, while C2 from the fusion method is a less clear image, since the fusion only is performed after each of these images is converted to grayscale and pre-processed. However, in each of these cases, it is also possible to control the lighting in the final image (C1 and C2), either by increasing the intensity (Fig. 3) or by decreasing the intensity (Fig. 4) using the application's intensity bar. In Fig. 3 the intensity has been changed to 102 while in Fig. 4 it has been changed to -102. The Wavelet fusion method (on right), on the other hand, remains identical for the application of luminosity (C3), in each of the cases. Finally, the Wavelet fusion method

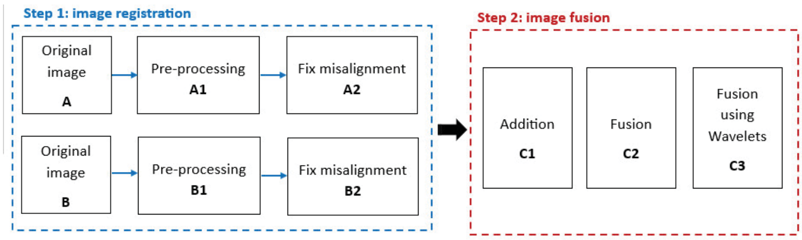

Fig. 1 Flowchart of the developed application

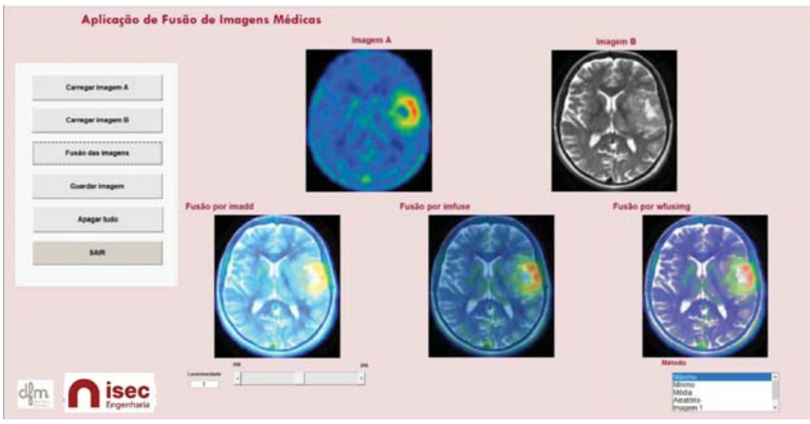

Fig. 2 Fusion of two PET and MRI brain images

combines the decompositions of the two original images using fusion methods applied to approximation coefficients. It is also possible to vary the filters applied to the Wavelet fusion image.

In Fig. 5 it is possible to observe the fusion with Wavelets of two images of the brain. Computed axial tomography (CAT) image A and PET image B with Wavelet fusion “Maximum” type.

Fig. 6 represents the fusion of images A and B of Fig. 5 using the four types in Wavelet fusion: ”Maximum” (a), ”Minimum” (b), ”Average” (c) and ”Random” (d). The first image has a higher lightness than the other 3 and in the case presented here, the fusion with the ”Random” type, in this case is the ”Average” type fusion.

Two other examples of the sequence of images obtained after applying the fusion methods implemented in the application can be seen in Figs. 7 and 8. The original images A and B and the Wavelet fusion obtained by three types: ”Maximum” (a), ”Average” (b) and ”Random” (c).

In Fig. 7 PET images (A) with contrast and CT image (B) obtained in [12] allow the fusion to more adequately display the two images together and extract different aspects of the anatomy. In Fig. 8 a CT image (A) and a PET image (B) with contrast (marker) obtained in [13], for the identification of small cancerous nodules. The patient is placed in the scanner, which, in addition to CT, has a nuclear medicine camera, which also captures the images emitted by the marker. Thus, the resulting color images accurately show the regions where the marker is absorbed.

In the developed application, it is possible to view the entire processing flow carried out, change the parameters through the menu and save the image in different formats. In this way, it is possible to monitor and analyze the development of certain pathologies through the comparison between images of different types obtained in different situations, being able to compare images of the same type or different types through fusion. It is intended to use this application in classes as a pedagogical support tool. This tool will allow teachers to create a more dynamic and motivating teaching environment for their students. And students will be able to visualize the effects of the techniques they learned in class in a real way. It will also be possible for teachers and students to make changes to functions already implemented or even create new functions, allowing to adjust the acquired knowledge, making the simulation environment adapted to new techniques and methodologies.

V. Conclusion

Medical image fusion is a method of recording the combination of multiple images into a single or multiple imaging modalities to improve image quality and reduce randomness and redundancy in order to increase the clinical applicability of medical images for diagnosing and evaluating medical problems [14]. This paper presents an application developed in MATLAB that allows merging two medical images from different modalities, for example the merging of a CAT scan image (in grayscale) with an image (in color), according to 3 different fusion models using different parameters. The objective of the developed application is to allow students of Biomedical Engineering to learn the basic methodologies and techniques of digital medical image processing in a real context. The possibility of customizing the application, including other image pre-processing or fusion

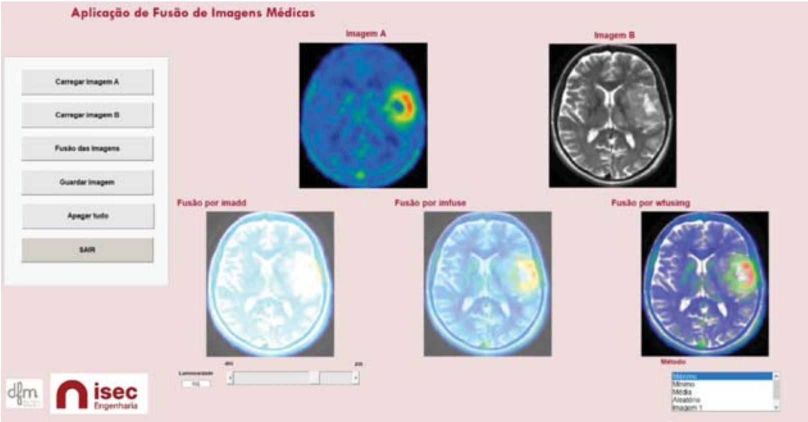

Fig. 3 Fusion of two brain images PET and RM with intensity level of 120

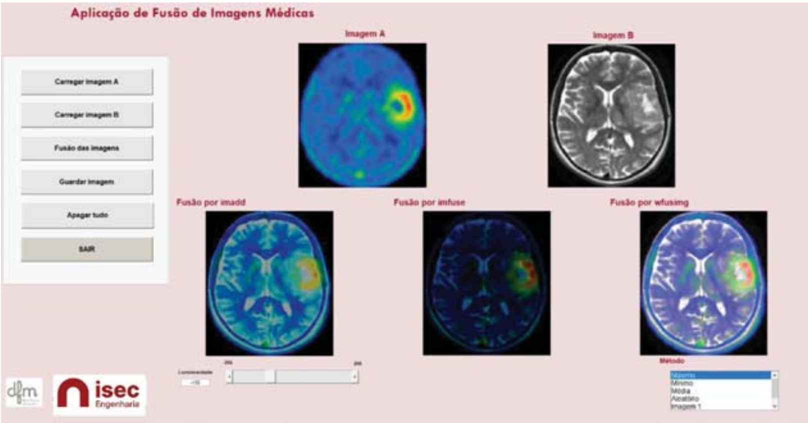

Fig. 4 Fusion of two brain images PET and RM with intensity level of -120

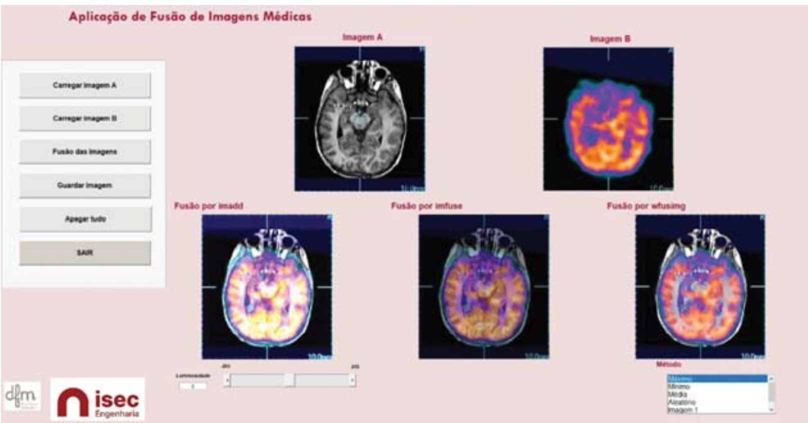

Fig. 5 Fusion of two brain images CAT and PET

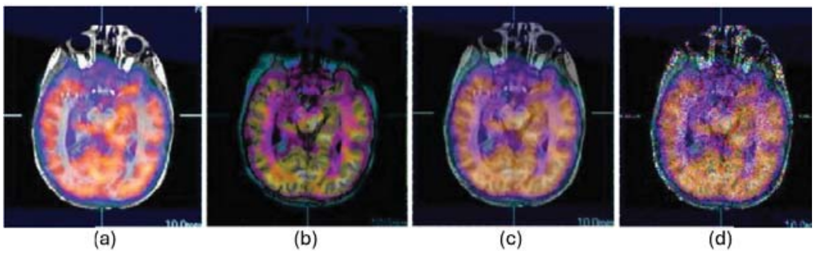

Fig. 6 Fusion two brain CAT and PET images using Wavelet fusion: "Maximum" (a), "Minimum" (b), "Median" (c) and "Random" (d)

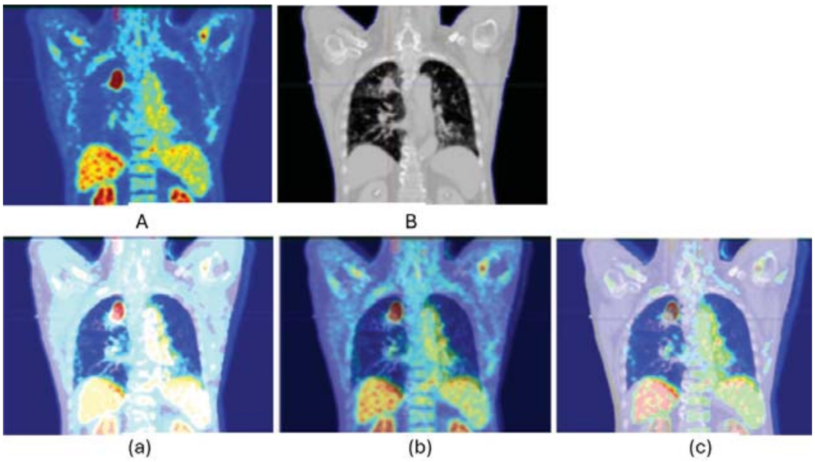

Fig. 7 Fusion of fluorodeoxyglucose (FDG) PET and a CT image using Wavelet fusion: ”Maximum” (a), ”Median” (b) and ”Random” (c) [12]

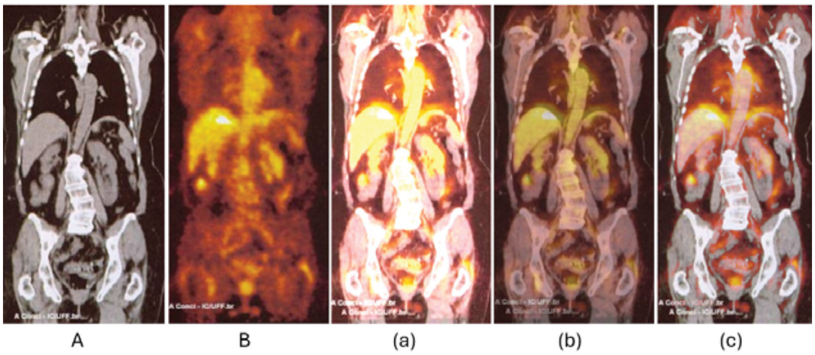

Fig. 8 Fusion of 2 images: CT image (A); PET image (B); fusion with wavelet methods maximum; minimum (a), median (b) and aleatory method (c) [13]

techniques, can be adapted by students and encouraged by teachers.

With the use of this application, teaching-learning in the classroom is ensured by learning in a simulation environment, allowing the student to acquire the different skills necessary for his training as a Biomedical Engineering.

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