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3DTHERMAL MODELS: A CASE STUDY OF THE NECK

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ABSTRACT

This paper demonstrates a computational tool that allows the imaging fusion and registration among different types of images. This approach allows the generation of a 3D thermal models combined with anatomy slices, enabling their 3D visualization altogether. This method can be used to assist in the identification of different pathological patterns, which can be verified based on this image fusion methodology. This research is based on the assessment and monitoring of the neck and its associated thyroid disorders, whether through the identification of nodules, goiter, hyperthyroidism and even cancer derived from these pathologies. The technique used here is based on the combination of three imaging modalities, which are: infrared images, anatomical images (magnetic resonance imaging (MRI) or x-ray computed tomography (CT)) and a 3D scanner (outer shell geometry). It uses a new approach for diagnosing, which proposes the fusion of infrared images with anatomy images for the investigation of pathologies in the neck/thyroid region. The method consists not only of an innovative technique, but also of a promising area of research, as it can be seen in the results presented here. Therefore, it is able to generate 3D thermal models which are wrapped with anatomical slices, being visualized altogether into a common reference system.

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INTRODUCTION

This research involves the assessment and monitoring of the neck and its thyroid gland disorders associated, whether through the identification of nodules, goiter, hyperthyroidism and even cancer derived from these pathologies. The focus here is related to the development of a computational tool to enable imaging fusion and registration of different imaging modalities, allowing to be visualized altogether.

This approach is being used for helping in the identification of different thermal patterns, which can be verified based on this imaging fusion methodology. Therefore, the employed technique here is based on the combination of three imaging modalities, which are: infrared images, anatomical images (magnetic resonance images (MRI) or x-ray computed tomography (CT)) and a 3D scanner (outer shell geometry).

The innovative aspect of this research is mainly related to the use of thermographic images (also called Infrared Thermography - IRT) for helping in the diagnosis and inspection of neck areas, due to endocrinology body changes. It is noteworthy that the infrared images assist in the inspection of physiological information of the body, related to the thermal variations, while most medical imaging systems (for example: MRI and CT) are restricted to providing only anatomical information, through sectioned images (slices) of the body.

In this paper we investigated the generation of three-dimensional thermal models, such technique is called 3D THERMO-SCAN (Souza *et al.*, 2015; Souza *et al.*, 2016; Krefer *et al.*, 2017). This methodology allows the verification of thermal changes based on the correlation with anatomical anomalies (such as nodules, goiter, cancer, etc.). Therefore, it leads to the interference of the respective impact among anatomical and functional information altogether, based on the differentiation between normal or pathology.

This approach is quite new, since there are no diagnostic methods that propose the fusion of infrared images with anatomy images for the investigation of pathologies in the neck/thyroid region. Thus, it consists not only of an innovative perspective, but also a promising research area, as it can be seen throughout the results here presented.

This paper is divided as follow: section II - a brief literature overview for contextualizing the 3D point cloud generation; section III - the methodology steps (covering since the preprocessing up to the 3D registration); section IV - the results and discussion obtained for a case study of the neck here presented; and finally section V – with the overall conclusion.

LITERATURE REVIEW

The detection of infrared radiation naturally emitted by the human body can be captured by means of infrared cameras. With the use of infrared thermography, it is possible to establish data collections of temperatures from various parts of the body. The imaging acquisitions are made by means of infrared cameras, which are positioned around the volunteer under analysis, to obtain images from various angles, thus generating a set of thermal images superimposed simultaneously. This enables the generation of a 3D point cloud, which represents a three-dimensional thermal shell (Aksenov *et al.*, 2003; Krefer *et al.*, 2017). The *Structure from Motion (SfM)* method arose from a need to obtain three-dimensional visualizations, aiming to establish a projection between overlapping images generating three-dimensional points (Souza *et al.*, 2015). The development of *Structure from a Moving Sensor (SMS)* techniques allow overlapping to cover the entire geometry of a given object/volunteer (Micheletti *et al.*, 2015). With the SfM method, one of the most popular ways to identify common points between scenes, is to make use of the *Scale Invariant Feature Transformation (SIFT)* technique, in order to establish spatial relationship into a 3D coordinate system (Micheletti *et al.*, 2015). For the identification of common points, through SIFT, it is necessary to have samples (i.e. image frames) correlated with another image sample, allowing visually different correspondences of texture, color and even temperature. The relationship between overlapped images into a 3D space system makes it possible to create a 3D model of the object being imaged (Ullman, 1979). The current *Multi View Stereo* (MVS) techniques make it possible to generate satisfactory3D models from a cluster of data, when compared to traditional methods involving only stereo correspondence. The MVS techniques, which employ calibrated images from different points of view, can generate a 3D object reconstruction. This approach delivers better results, with better data resolution as well, especially when compared to the extraction of 3D information from 2D images (Rebecq *et al.*, 2016; Ullman, 1979). That is why in this research we applied the SfM technique, which is part of the MVS approach, which delivers good results from the neck of volunteer's data.

METHODOLOGY

There are different methodology steps, which are: (A) Images Acquisition; (B) Preprocessing; (C) Structured from Motion (SfM) Processing, (D) 3D Alignment and (E) 3D Registration. Such steps are detailed here.

A. Images Acquisition*:* At this stage, various imaging modalities of the neck region of a volunteer are acquired. First, sliced anatomical images are obtained (which can be either MRI or CT), according to the clinical indication. Then, the next step is the acquisition of the infrared images (with a thermal camera) and the outer geometry (based on a 3D scanner). In this study, the anatomical images were from a magnetic resonance imaging (MRI), which were obtained from a 3T Siemens equipment (*Magnetom Skyra*). For the infrared images acquisition, a period of acclimatization (approximately 15 min) was carried out, in which the inspected region must be uncovered. An infrared camera (FLIR, A325) is being used. This camera has wavelengths sensitivity from 7.5 to 13 μm, and its records temperature ranging from -20 to 120 ºC, with a thermal resolution of 0.05 ºC. It also records movies at a rate of 30 frames per second, generating images with a resolution of 320 x 240 pixels. The lens being used has a nominal focal length of 18 mm. The 3D scanner used in this study is based on structured light projection modality. The system employed is the GEMINI SF (Small Field), lately from CREAFORM company, which is quite portable. This system enables to collect about 2 million of 3D points at once (i.e. in X, Y and Z coordinates), which are acquired in about 0.6 s. In terms of technical specifications, the system covers a field of view of 460 mm x 340 mm, a depth of field around 45 mm and in terms of resolution it has 0.4 mm in X and Y coordinates and 0.2 mm in Z coordinate. The working distance ranges from 950 mm to 1100 mm. This 3D scanner modality also provides the texture (photography) to be visualized together with the 3Dmodel generated.

B. Preprocessing: The acquisition of several infrared images (into a continuous video format) of the neck region made it possible to evaluate and analyze these images. So, this stage is also responsible for the manipulation of the images, including its conversion to other file formats, which are necessary for the further computational process (section III-C). So, after the thermal images acquisition, we obtained a continuous video format, saved in the SEQ file, which is then imported to FLIR Tools software for the initial file's conversion. The temperature of each pixel of the thermal images reconverted/saved in a text file (CSV format). Through the MATLAB software, we can analyze the CSV files and convert them to MAT file as well. After this conversion of the formats and the frames selection of the sequence (i.e. the complete video collected), we move on to the point cloud generation stage (according to the *"Structured from Motion"* (SfM), presented at section III-C).

C. Structured from Motion (SfM) Processing: The *Structured from Motion (SfM)* stage involved the use of the SfM methodology, which consists of a set of techniques that are used for three-dimensional reconstruction only based on2D images. The interface being used at this stage is called *Visual SfM* software, which is responsible for processing the frames. The idea here is to generate a 3D point could from a set of 2D images of a volunteer. With the SfM methodology, it is possible to determine both the 3D coordinates of the object in the space (obtained through the various 2D images/frames), as well as the positioning of the cameras in space. The SfM methodology is based on "feature extraction" and the generation of a 3D point cloud, which leads to the 3D reconstruction of the external surface of the volunteer under

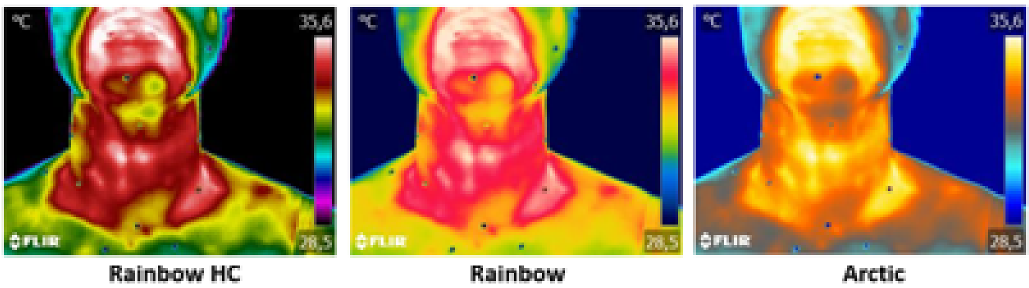

Figure 1. Illustration of afrontal thermal image, represented by different palettes

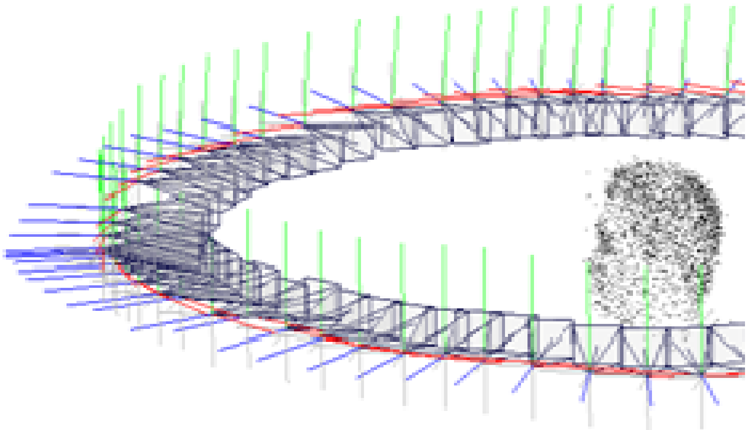

Figure 2. Illustration of the point cloud, surrounded by the camera positions

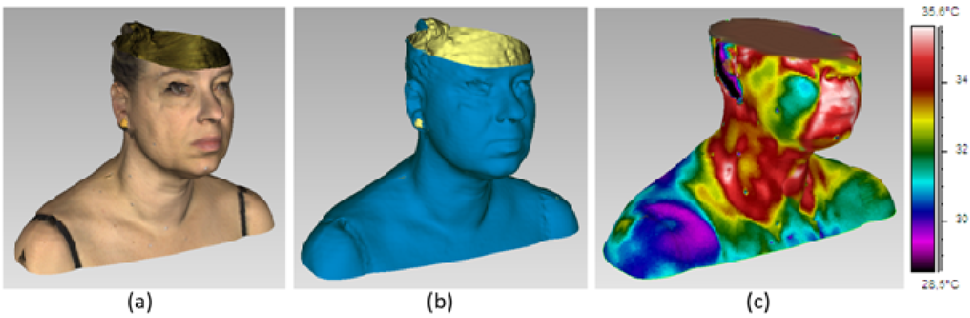

Figure 3. Visualization of the 3D models of the face/neck region of a volunteer: (a) 3D textured model; (b) 3D model with no texture (only the 3D mesh); (c) 3D thermal model (i.e. the 3D thermal outer shell) - obtained after the alignment and the incorporation of the infrared images.

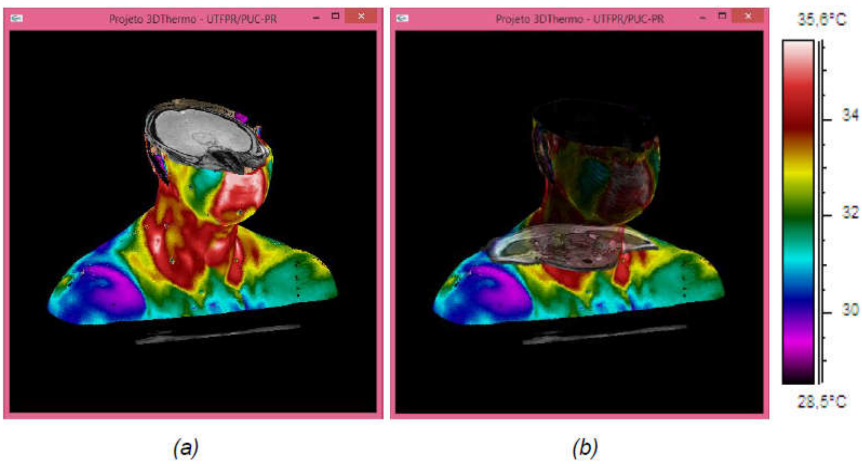

Figure 4: Complete 3D model, based on the proposed methodology (3D THERMO-SCAN). This model shows the 3D visualization illustratingsome axial sections: (a) Complete 3D model and (b) The 3D model with a transparency

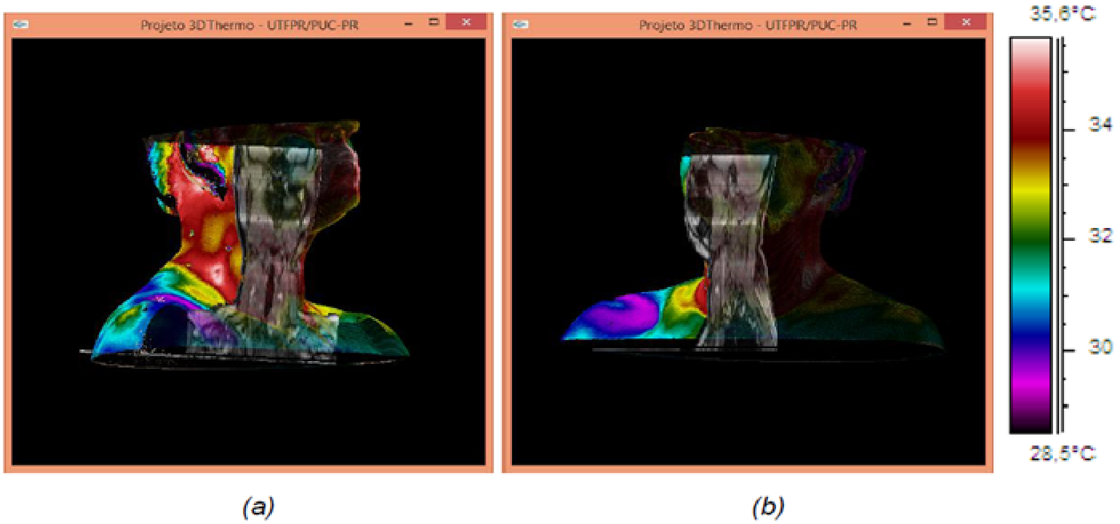

Figure 5: Complete 3D model, based on the proposed methodology (3D THERMO-SCAN). This model illustrates the results after the fusion and registration of all imagingmodalities in:(a) Sagittal and (b)Coronal sections – including its transparency as well

analysis (Szeliski, 2010 and Furukawa & Ponce, 2010). One of the main purposes here is to acquire a sufficiently dense and complete point cloud (including the anatomic region obtained during the data/image acquisition). To achieve this, we sought to use the type of images with the best possible contrast (referring to the importance of the preprocessing stage (section III-B).

D. 3D Alignment: In this stage, the dense 3D point cloud is aligned and merged with the 3D geometry (obtained from the 3D scanner).As a result of this step, the thermal images are projected and incorporated onto the scanner's 3D model. Therefore, the final texture is related to the infrared images texture (i.e. the temperature).Therefore, this stage basically consists of a "3D thermal wrapping", allowing to obtain the 3D thermal model (i.e. the 3D thermal outer shell).

E. 3D Registration: In this final step, a complete 3D model is obtained, enabling the achievement of the methodology called 3D THERMO-SCAN(Souza *et al*., 2016).Therefore, this computational last procedure is responsible to merge and register: the 3Dthermal outer shell (containing the 3D thermal geometry -obtained from section III-D) together with the MRI or CT images, incorporated altogether for a combined 3D visualization. At this stage, the main procedure is to perform a coordinate system transformation, which is carried out within Geomagic wrap software (3D Systems Inc., 2015), based on a rigid alignment, called affine registration. This technique is responsible for keeping both models together: (1) 3D thermal shell, aligned and registered with (2) the 3D MRI images/slices. This step is a 3D registration between both 3D models. As outcome, we can open both files altogether to be visualized at our own 3D visualization interface.

RESULTS AND DISCUSSION

This section presents the results obtained within this research, which are related to the case study being inspected. Therefore, the results are presented based on the order of the stages previously shown at the methodology section.

A. Images Acquisition and Preprocessing: The images employed in this case study are from MRI anatomical images and infrared (IR) thermo graphic images of a 40-year-old female volunteer with thyroid nodules and goiter diagnosis. Regarding the preprocessing stage, it was employed the type of images with the best possible contrast, to enable the best features extraction. To illustrate, Figure 1shows the same profile image viewed on several thermal palettes. There is a variety of palettes and it is even possible to create your own palette. Another important remark in this step is the visualization of the image, since it is possible to change the minimum and maximum values of the scale (i.e. the image range). In the case of Figure1, the temperature variation ranges from 28.5 ºC to 35.6 º C. It is worth to mention that this range can be changed to highlight the regions under study, focusing on the inspection for the clinical applications. In this case study, the warmer regions are detected and localized due to the thyroid nodules of the volunteer under analysis.

B. SfM Processing and 3D Alignment: During this stage, based on the SfM methodology together with the 3D alignment, it was generated a 3D thermal outer shell geometry, which is a 3D thermal model. So, it was initially generated a 3D point cloud by the Visual SfM. Figure 2 illustrates the point cloud (located in the center and the position/locations of the cameras as well). During the 3D alignment, the 3D point cloudis replaced by the 3D surface mesh (in this study obtained from the 3D scanner – Figure 3(a) & (b)) - (keeping the same location of the cameras in the space). Therefore, this represents the 3D alignment process, which enables to generate the geometry of the 3D thermal model, as shown in Figure 3(c). For further understanding of this whole process, Figure 3 shows the 3D geometry of the face and neck for this volunteer (case study). After acquiring all the imaging modalities (i.e. thermal images and 3D geometry (by the 3D scanner)), the merging of these two imaging modalities was based on the 3D alignment, performed in MeshLab (Cignoni, Paolo, *et al.* 2008). This image fusion process consists of initially obtaining a 3D geometry model (from a 3D scanner), which represents a very precise external geometry (shown in Figure 3 (a) and (b)) – considered a gold standard approach to obtain 3D models. Then, next the thermal images are aligned and superimposed into the 3D geometry, as it can be seen in the generated 3D thermal shell, illustrated in Figure 3 (c). This methodology will enable us to proceed to further clinical evaluations, which are much better than the inspections based only at bidimensional single thermal images (as shown in Figure 1).

In this case study, there is an issue to be inspected over this volunteer, since she has a thyroid dysfunction (i.e. multiple nodules located inside the thyroid), which gives this temperature variations.

C. 3D Registration: The complete model results from the registration of the three imaging modalities already acquired. Such modalities are: the 3D geometry (from a 3D scanner), the infrared images (in a continuous video format) and the MRI anatomy images. The initial processing here is performed in Geomagic wrap [3D Systems Inc., 2015], to provide that all these imaging modalities are all aligned, registered, and visualized in to the same coordinate system. The final 3D model represents a complete model (3D THERMO-SCAN methodology), which involves the region analyzed as a whole (including both the external thermal 3D geometry and the inner MRI images), as illustrated in Figure 4.

Therefore, this stage shows the results obtained from the 3D registration step, using the 3D visualization interface developed for this research. So, it shows the complete 3D volume after the registration between the 3D thermal model and the MRI images. This 3D model emphasizes the visualization of several axial sections (with and without transparency), as represented in Figure 4 (a) and (b). On the other hand, Figure 5 (a) and (b) presents the 3D model specifying one of the sagittal and coronal sections respectively (with transparency). Such transparency was used only to delimit the total region of the reconstructed 3D model and then it facilitates the identification of the region to be inspected.

For the volunteer presented here in this work, diagnosed with thyroid nodules and not yet undergoing hormonal treatment, representing a good case study to validate the methodology and evaluate the possibility for identification and correlation between the nodules, both in thermal and anatomical images (MR). Therefore, this methodology provides tools to enable further important clinical correlations.

The literature (Helmy *et al.*, 2008; Rossato *et al.*, 2015; Alves & Gabarra, 2016 and Gonzalez *et al.*, 2017) also presented some studies showing clinical applications within infrared images to investigate the temperature variations at the neck, due to the thyroid disfunctions, such as nodules and cancer. Helmy *et al.* (2008) also mentions that most of the thyroid pathologies being investigated in the clinical approach are related to hyperthyroidism. This is mainly due to the infrared radiation emitted by the thyroid gland, especially because of the hyperactive nodules (represented by the higher temperatures of the investigated region).

Conclusion

Based on the generation of complete three-dimensional thermal models, it is possible to visualize much more details and structures, including different imaging modalities altogether: anatomy (MRI), functional (infrared images) and also a precise external 3D geometry (from a 3D scanner system). Therefore, the 3D registration proposed at this paper has the advantage of including anatomical and infrared data, which allows the verification of the exact location of the inner structures. Thus, it enables the correlation of the inner nodules through the imaging fusion/registrationamongall the imaging modalities involved. It is worth mentioning the importance of this approach, which provides the incorporation of good spatial resolution through the MRI images (anatomical information) within the infrared images (functional information), although having low spatial resolution. So, one imaging modality complements the other in terms of supplying its deficiencies.
The case study presented at this paper has shown a volunteer with multiple nodules inside the thyroid, which proved the availability for using the combination of different imaging modalities, among them infrared images to detect and inspect thyroid disfunctions for clinical correlations. The analysis of the 3D thermal complete model (i.e. the 3D THERMO-SCAN model, as shown in Figure 4 and 5) were carried out, allowing the 3D visualization of the whole neck region to be investigated, according to the thyroid pathology mentioned (nodules). However, additional data, from other patients/volunteers, are still needed to expand this research for further clinical correlations and pathologies. Therefore, as future perspectives, we mention arecent collaboration with a clinical team of endocrinologists from the university hospital, who are helping us with more volunteers to expand this research.

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