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# Image Fusion Improvements applied at the Generation of 3D Thermal Models

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*Abstract*— **The application of multimodal image registration to various medical applications has been investigated. Image fusion involving 3D thermal and MRI/CT images allows the extraction of both functional and anatomical information, which may become a powerful tool to aid in clinical diagnoses.**

**This paper presents innovations at the image fusion methodology, which currently requires that both imaging modalities are represented and visualized at the same 3D viewing projection. The proposed solution is based and compared with two different viewing projections: orthogonal and perspective. The methodology requires that the thermographic images (or photographs) are visualized in the orthogonal view, in order to match with the 2D projected images (using range images) from MRI/CT.**

**The results obtained have shown significant improvements in the 3D thermal models, when compared and evaluated with the perspective approach. This allowed the generation of more accurate 3D models, which match both the geometry and texture (functional temperature information). Since it is desirable to combine or unify more than one imaging modality, these 3D multimodal models may have a strong impact in many clinical applications.**

## I. Introduction

The integration of multimodal images, such as anatomical and functional modalities, may improve the accuracy and reliability of the image diagnosis. This integration may provide a detailed analysis of the different structures and at the same time it supplies information about physiology [1, 2].

In literature there are references to systems called multi-camera based 3D infrared imaging systems [3, 4]. Such systems use several high resolution cameras, both photographic and thermal cameras [5]. Other systems also make use of 3D scanners together with these high resolution cameras [6]. Applications of these multi-camera systems can be found in the industry and medicine. Some examples are the systems described by Aksenov et al. [7] and Ju, Nebel & Siebert [8]. Applications to the automotive and manufacturing industry are presented in [9]. Gray, Dumont & Abidi [10] used different images that are acquired with the object placed at different distances from the camera (multiple range images) and with different illumination levels (resulting in different gray levels´ representation, i.e. intensity images).

However, the 3D infrared models generated by these systems incorporate only the external geometry, without including the inner information of the object being imaged. In the case of medical images, the information about the structure of the internal anatomy, obtained from CT or MR images, is crucial for medical diagnosis. Therefore, a 3D model of the body that incorporates over its surface the body temperature is an additional tool for medical diagnosis.

The 3D THERMO [1, 2] combines two different imaging modalities: 2D Infrared Images (IR) (skin temperature changes) with Magnetic Resonance Images (MRI) or Computer Tomography (CT) images, in order to obtain 3D thermal models. Regarding the 3D image visualization process, there are two different image viewing projections: orthogonal and perspective. The novelty of this study exists in the use of the orthogonal, instead of the perspective projection. This is applied to the infrared images under the orthogonal approach for the registration step. This is necessary since the 2D projected images, from MRI/CT, are also orthogonal images.

In order to validate the improvements observed in the new 3D thermal models, some experiments were performed to verify the correspondence of the external surface really to the inner anatomical structure. For this, several reference fiducial markers were placed over the surface of a test phantom. These markers were used as points of reference to verify the orientation and positioning of the phantom, during the thermographic images (photographs) acquisition. Finally, the new model is reconstructed and visualized using data from a volunteer.

## II. Methodology

### A. *3D THERMO Steps*

The 3D THERMO methodology is divided in five steps:

**Step 1 - 2D Image Projection:** The MRI (or CT) slices are added up, forming a 3D model. To register the thermographic images over this 3D model, four grayscale images are built from the 3D model. These images are 2D projection planes (using range images [11]), where the pixel values represent the distances between a projection plane and the object contour line, for each MRI or CT image slice. It is necessary at least, four 2D projections around the 3D model.

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These 2D projections represent the viewing of the 3D model at 0º, 90º, 180º and 270º.

**Step2 - Thermography Orthogonal Transformation:** It is necessary to acquire at least four thermographic images so that the temperature information can be used to wrap the whole 3D model. These thermographic images are acquired roughly at the same viewing of the "2D projections", i. e., at 0º, 90º, 180º and 270º. Originally, the small differences between the orthogonal and perspective representation were not considered [1, 2]. However, further experiments proved that even such a small difference has an effect on the final 3D model. Thus, to improve the accuracy of the final 3D THERMO model, the termographic data must be converted to orthogonal viewing [12, 13], before it is registered to the orthogonal 2D projection.

**Step 3 - Image Registration:** An affine transformation [14] is performed between the 2D projections (step 1) with the correspondent orthogonal viewing of the infrared images (step 2). Affine transformation achieves the best image registration for the 3D THERMO since not only includes the translations and rotations, but also the scaling of the images to be registered.

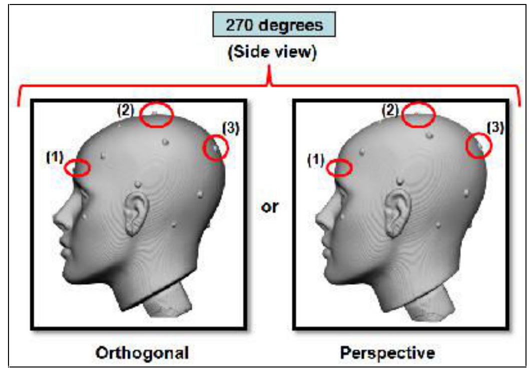
**Step 4 - Data Fusion:** After registration, the contour line of the object of each MRI/CT slice is updated with the thermal information, represented by the different temperature changes on the external surface. This information is stored in a PLY (Polygon File Format).

**Step 5 - 3D Visualization:** This last step consists of the three-dimensional (3D) visualization, showing a 3D model containing both the anatomical information (internally) and skin thermal variations (externally). In order to provide the correct volume dimensions, in the 3D reconstruction, the "pixel spacing" and "spacing between slices" parameters has been introduced. These are obtained from the DICOM MRI/CT file images. The output is a triangular surface mesh which is saved in a PLY file.

*B. Orthogonal versus Perspective Viewing Projection*

Fig. 1 illustrates the differences between the orthogonal and perspective representation (step 2). It gives an insight into how the different 2D viewing projections affect the final 3D THERMO model. In Fig. 1(a) and 1(b) the phantom side view (270º) at the orthogonal and perspective projections, are shown respectively. The markers added at the surface of the phantom assist in recognizing the differences between the projections. For instance, in the perspective projection, Fig. 1(b), the markers 1, 2 and 3, located on the borders, appear as they were deviated to the backward of the scene, and some of them are even occluded (label 1 in Fig. 1(b)), when compared to the orthogonal projection. For the image registration process, the desired location of the markers should be visualized in the orthogonal viewing projection.

The new approach (employing the orthogonal view) improves the precision of the final/reconstructed 3D THERMO model.




(a) (b)

Figure 1. Representation of both viewing projections: (a) Orthogonal, & (b) Perspective - showing the side view (270 degrees).

Two experiments were performed to investigate how the different input images affect the image registration (step 3) and consequently the final 3D THERMO model.

- **Experiment 1 – Perspective Viewing Projection:**

In this experiment, the images obtained from the infrared camera and the 2D projections were registered. Thermography images are generated based on a perspective center (with a pinhole camera). Therefore, such images are under a perspective point of view. On the other hand, the 2D projections are obtained with lines that are perpendicular to the projection plane. After several inspections based on the visualization of the markers, it was concluded that there was an error not from the affine transformation employed, but from the discrepancy in the viewing projections obtained from the original infrared images (perspective view) and the 2D projection images (orthogonal view).

- **Experiment 2 – Orthogonal Viewing Projection:**

To deal with the problem observed in the Experiment 1, a new approach (step 2) has been followed - to convert the infrared images from the perspective to the orthogonal viewing projection, with the use of an orthogonal transformation [12, 13].

Fig. 2 illustrates the image registration (step 3) process. In this case, the thermographic image is visualized in the orthogonal viewing projection (Fig. 2(A)) and the 2D projected image is shown in the same orthogonal view (Fig. 2(B)). This registration generates the image presented in Fig. 2(C).

It is important to notice that in the new approach, both imaging modalities: the thermographic and the 2D projected images - are presented in the same orthogonal viewing projection.

This example illustrates the image registration at the side view (270º); however the same registration procedure must also be performed at the other views, 0 º, 90º and 180º, between the respective infrared images and the 2D image projections.

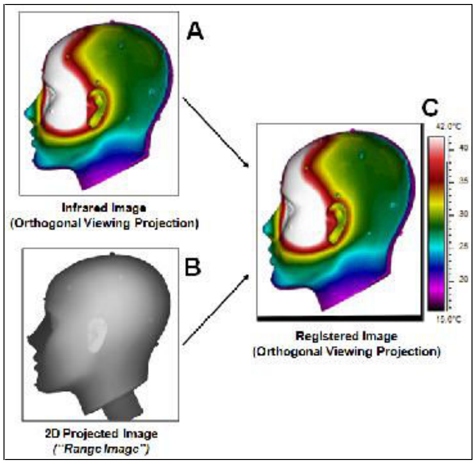



Figure 2. Experiment 2: Image Registration at the orthogonal viewing projection.

## III. RESULTS

The 3D models were reconstructed by both methods (the perspective and the orthogonal approach). The results obtained are shown in Fig. 3. In Fig. 3(a) a mismatch between the markers and the texture, represented by the thermographic images can be clearly observed. In contrast, Fig. 3(b) shows that the reference markers are properly placed at the right positions. Based on the analysis of the 3D external geometry and the markers (located on the surface), the results demonstrate that by converting the perspective thermographic image to an orthogonal viewing projection, a better solution for the two imaging modalities´ registration can be achieved.

The next example involves the reconstruction of a 3D model of the wrist of a volunteer diagnosed with arthritis-rheumatoid. Before presenting the actual 3D model obtained, it is worth to show the full set of images for this case study. Fig. 4 illustrates: (a) the original infrared images (acquired with a calibrated infrared camera - FLIR ThermaCAM E320), (b) the 2D projected images (obtained from the MRI image slices), and (c) the registered images (under the orthogonal viewing projection), which are represented according to all the angles (0º, 90º, 180º and 270º).

The 3D thermal model showing in Fig. 5 was obtained by applying only the orthogonal view. Fig. 5(a) and 5(b) illustrate two different cross-sections (transversal images) of the same structure (wrist), showing different MRI slices, that were obtained by sectioning the obtained 3D model. The inspection of the 3D thermal model provides additional evidence that there is a lesion in the inner anatomical structures, which is then reflected externally by the clear brightest spot on the hand´s posterior (dorsal) view. This is reflected in a higher average temperature, if compared with the rest of the wrist. This conclusion was based on the analysis of the external thermographic image surrounding the model.

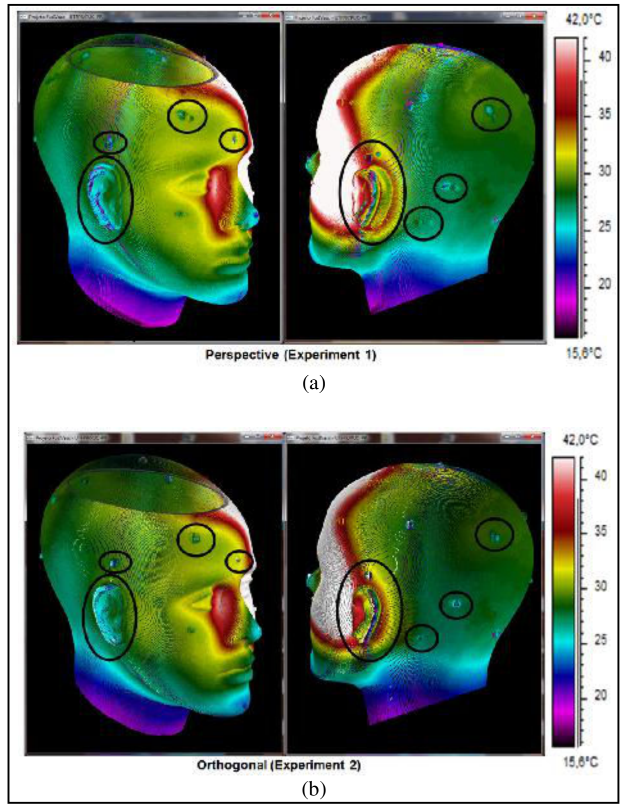



Figure 3. 3D THERMO visualization - showing the 3D thermal model generated for the head phantom, based on the different viewing projections: (a) Perspective (Experiment 1) and (b) Orthogonal (Experiment 2).

Additionally, the MRI based diagnosis by a specialized physician (radiologist) also confirmed that there was an internal lesion, a synovitis. This lesion is represented by the inflammatory and chronic nature of the radio-ulnar and carpal joints that can be observed at the MRI images. Although, the discussion of the details of the clinical findings is beyond the scope of this paper, it is clearly shown that the fusion of different imaging modalities may further assist in medical diagnosis.

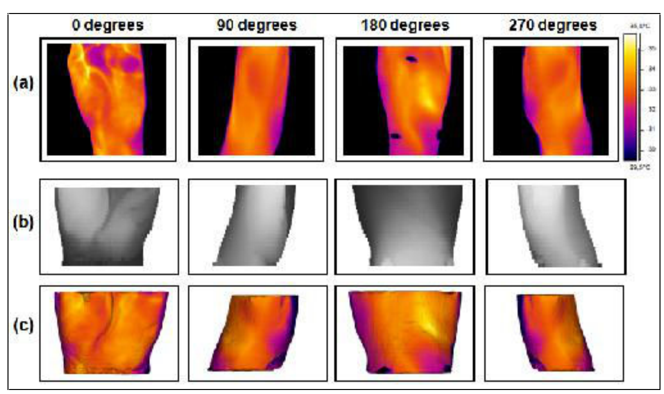
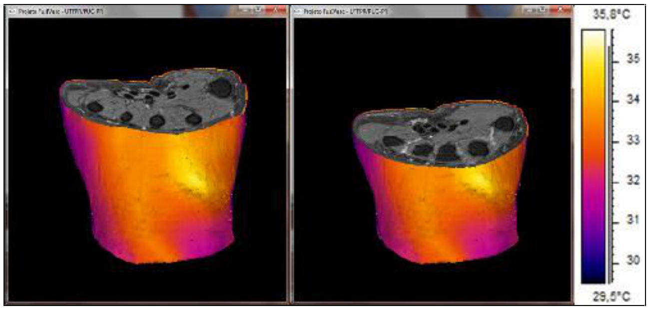



Figure 4. Full set of images showing: (a) Original termographic images, (b) 2D projected images, (c) Registered images (under orthogonal view).

The advantage of this methodology lays on the fact that it enables complex analyses based on a single 3D model that combines two types of information: the anatomical (MRI or

CT slices) and the functional data (infrared images).In such way, by slicing the 3D model (as shown in Fig. 5(b)) it is possible to observe the differences in the anatomical structures overlaid by the body surface temperature.




(a) (b)

Figure 5. 3D THERMO visualization of a volunteer´s wrist.

## IV. Discussion

The 3D THERMO tool, based on the generation of a single and unique 3D model, allows supplementary means for clinical inspection, once that the single imaging modalities by itself would not be able to provide such clear findings. Therefore, the importance of the method consists in providing more precise and clear diagnosis.

Other clinical applications are being explored, such as, lesions causing inflammation at the feet (tibial synovitis), knee and shoulder.

The innovative part of this project is the use of the orthogonal viewing projection in the 3D THERMO reconstruction, improving the texture location associated with the thermal images, generating more reliable 3D thermal models. The experiments presented at this paper validated and compared the orthogonal proposed methodology.

To date and to the best of the authors' knowledge there is no other method reported in the literature that presents the generation of such 3D thermal models. For instance, the studies presented by Colantonio et al. [6], Grubiši et al. [3, 4] and Viana et al. [15] show the reconstruction and utilization of an external 3D thermal surface without incorporating any anatomical information.

## V. Conclusion

The proposed methodology that utilizes the orthogonal viewing projection (instead of the perspective view) results in a more consistent and realistic image registration. The advantage of this approach is that allows the simultaneous visualization of both the internal anatomical structures (provided by MRI or CT) and the functional information (represented by the infrared thermal images).

This innovative approach could assist clinicians in the diagnosis of different pathologies. It could eventually become a powerful tool in 3D visualization, inspection and image diagnosis by correlating the body´s temperature with possible dysfunctions in the inner structures.

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