A NEW METHOD FOR GENERATING 3D THERMOGRAPHY MODELS

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ABSTRACT
Medical Infrared Imaging (IR) is a noninvasive diagnostic method that allows the examiner to evaluate and quantify temperature changes on the skin surface, which is reflected as any abnormal internal temperature variation. However, thermograph images are essentially a 2D technique and its image does not provide useful anatomical information associated with it. Therefore, this paper presents a new method for combining 2D Infrared Images with Magnetic Resonance Images (MRI) and/or Computer Tomography (CT) images, employing an image registration (fusion) methodology. As a result, it is generated a new hybrid 3D model, denominated 3D THERMO. This new 3D model involves the visualization of a rendered image, which has the additional of being generated based on multi imaging modality: the temperature (functional information) originated from the thermal images (IR) and also the MRI or CT images (anatomical or structural information). This innovative tool will help improvements in clinical applications, such as medical diagnosis and for monitoring treatment of certain pathologies.

KEY WORDS
Infrared Imaging (IR), Thermography, Magnetic Resonance Imaging (MRI), Computer Tomography (CT), Image Registration, Image Fusion.

1. Introduction
Infrared imaging (IR), also called thermography, is a diagnostic technique that is based on the human body surface temperature changes. Extremely sensitive infrared sensors are used to measure and produce pseudo colors or grayscale images of the surface temperature.

Medical thermography is becoming an important technique in order to assist in the diagnosis of several diseases. Some medical areas, in which thermography is being largely employed, can be mentioned [1], [2]:

- Oncology: in the diagnosis and treatment of cancer, once not only the lesions pre-cancer but also the actual cancerous tissues show a vascular increase and consequently an increase in the temperature of the affected region. In this scenario, the thermographic images with good resolution help in identifying early cancer. As a classical example, it is mentioned the breast cancer, in which the thermal images can point out cancer even when mammography fails.
- Vascular disorders: especially the ones related with bleeding related disorders. For instance, thermal images show deviations provided from the blood vessels, in which can certainly help in the identification of hemorrhage and coagulated regions.
- Respiratory diseases: related with difficulties coming from the respiratory system. In this case, thermal images provide an important tool to observe physiological differences in the respiratory organs.
- Neuromuscular and skeletal systems disorders: small crack in a bone and neuromuscular disorders can be captured with a high resolution infrared system/camera, helping in the identification of neuromuscular disorders.
- Surgical procedures: it is related with invasive procedures (surgery) with the final aim of treating the patient. In this area, the use of thermal images may help and guide surgeries.
- Tissues’ Vitality: Finally, it is mentioned the vitality of the tissues as a whole. In this case, the thermal images can check the irrigation of the blood vessels in order to provide also a good oxygenation of the surrounded tissues.

Infrared images may add relevant information complementing other methodologies at the medical investigations [3]. Some advantages are mentioned: it is a quick and non-invasive method, since it does not employ any kind of radiation and neither imaging contrast. Further it does not need any physical contact with the patient. However, thermal images may have some limitations, such as: the detection of the temperature variations are recorded only from the external surface; it does not provide any representation of the anatomical structure being analyzed, and it provides only two-dimensional (2D) images.

Figure 1 illustrates an infrared image of a volunteers’ head/face, showing some punctual temperatures in specific regions (areas) of the face.

In the last years, the use of thermal images for clinical applications has greatly increased. For example, it is possible to mention several recently published papers: [1], [2], [4], [5], [6], [7], [8].

It is also pointed out significantly contributions, research-oriented with applications of thermography in neurosurgical procedures. Mainly surgeries performed
with the cranium open, in which it involves the analysis of the intra-cranial vascularisation for repair and also removal of the affected areas (either benign or tumors). In these circumstances, once the outer surface of the brain is exposed, the use of thermograph images or Digital infrared thermal imaging (DITI) represents an additional method of real-time evaluation.

Figure 1. Infrared image of a volunteers’ face, showing the temperatures in specific regions/areas.

In order to provide more concrete examples, it is mentioned contributions of [9], [10], in which it is described the monitoring of the local neuro-physiology. Especially, when there is the need of checking variations due to local perfusions (due to the abnormal vascular increase in the affected areas). Therefore, there are several clinical applications employing the monitoring through thermal images at surgical procedures. However all this refers to two-dimensional (2D) thermal images.

A new method for generating 3D Thermal images, called 3D Thermo, was already presented [20]. This method consists of fusing (adding) two imaging modalities (CT - Computer Tomography or MRI - Magnetic Resonance Imaging) and thermal data. In this fusion, the thermal data are added to the object contour lines (borders) in the MRI/CT image slices.

In this paper, we present new results of the three-dimensional (3D) thermal method.

1.1 3D Thermography

The literature still reports few related systems that employ multi-camera based real-time 3D infrared imaging techniques.

Usually these systems consist of either one or more infrared cameras synchronized with high resolution digital color cameras or 3D laser scanning systems. Thus, these systems are only concerned with the surface mesh, not showing any internal structure, and are mainly used for industrial applications.

Examples of such systems are the ones described by [11] and [12]. In these references, it is presented a 3D thermal model, resulting from the combination of 3D visual images (geometry) and thermal imaging, which allows the generation of combined 3D thermal models. [13] shows a method which classifies the 3D distribution from infrared images, having applications in the automotive and manufacturing industry. In their method, they apply a computer vision approach in order to build the thermal distribution using only the infrared images. The method presented by [14] employs the use of multiple range images and also intensity images to create combined surface meshes (external geometry) together with texture maps. Their method assumes that there are multiple range and intensity image pairs of an object, which helps into the registration. Such registration (based on a volumetric method) is responsible to merge all data into a global coordinate system, resulting in the 3D thermal textured models.

The novelty of the proposed method is not only to have the external thermal surface but also bringing together the inner structure of the body. Therefore, it is possible to provide to medical doctors a visualization tool that can be used to correlates the external temperature in the body surface with an eventually internal organs’ dysfunction.

2. Materials and Methods

Nowadays, the information integrated from two or more imaging modalities of the same patient, mainly involving structural (anatomical) and functional information, is a tendency in terms of medical image processing and regarding diagnosis it provides extreme advantage over singular methods [11], [15], [16], [17], [18]. Image fusion – merging anatomical & functional modalities, provides a single image which certainly assists in the diagnosis and consequently in the therapeutic process.

2.1 3D THERMO: Definition

The new computational tool described here provides a new imaging modality - 3D thermography, which is a hybrid model, named 3D THERMO. It consists in the fusion of images coming from thermography and MRI or CT images [19].

3D THERMO is based in an innovative methodology of fusing MRI/CT images with thermal images. The image fusion methodology requires that the 2D thermal images (obtained from different views and angles, around the subject under investigation) have to be overlapped to all the MRI/CT slices, which “stack together” creates the combined (fused) three-dimensional (3D) object. Figure 2 shows the image fusion process between thermal and MRI/CT images, which is described at the following steps [20], [21]:

(a) The first step is related to the 2D image projection of all the tomographic planes (MRI or CT), in four angles (0º, 90º, 180º, 270º), based on a similar technique called range image [22].
(b) The image registration is performed between the 2D image projected (based on all the four angles) and the thermal images (at the same angles). The affine
A transformation technique is used to perform this registration for all the four angles.

(c) The border of the MRI/CT slices are overlapped with the thermal images (fusing the MRI/CT with the thermography images).

(d) The last step consists in the three-dimensional (3D) visualization of the object under study, employing both temperature and structural information.

In Figure 3, a diagram illustrates how the 2D projection is obtained from the MRI/CT slices. First, it is determined the external contour of the object. Any thresholding technique is applied to each MRI slice. Then, for each orthogonal thermography view (at the same angles: 0°, 90°, 180°, 270°), a correspondent 2D projection of the reconstructed 3D MRI volume is created (employing a process similar to Range Image Technique).

An histogram equalization on the 2D projected images is applied.

During the thermographic image acquisition the object must be upright and the camera axis perpendicular to an imaginary vertical plane the cross the object center. In Figure 4, it is shown the thermographic image, the 2D projected image and the corresponding registered image.

For such registration, it is employed the affine transformation, which consists in mapping parallel lines in both images to be registered. It requires to manually select at least three sets of points in each image to be matched, as shown in Figure 4. In this research, it was employed a Matlab function to provide the affine transformation/registration.

![Diagram showing the proposed method - 3D THERMO](image)

Figure 2. Diagram showing the proposed method - 3D THERMO, which consists in merging the IR thermography data images with the MRI dataset.
Medical Images (MRI or CT Slices)

- Manual Threshold
- 2D Projection
- Histogram Equalization

Figure 3. Image Processing techniques applied to the original MRI/CT slices, in order to obtain the 2D Projected images of all the views.

Figure 4. Representation of the registration step (b) performed between the thermographic image and the 2D projected image.

Figure 5. MRI Slice with the thermographic border, showing in the magnified area the detail of the borders with the temperature information.

3. Results

Up to now, this new methodology was validated with some experiments, such as: test objects, mainly phantoms, and a head phantom for radiotherapy treatment. Also an experiment was performed with a volunteer that was exposed to MRI and thermography [19].

The final 3D thermo algorithm is:

1) Generation of the four 2D projections (based on the four angles: 0º, 90º, 180º, 270º) from the phantom CT dataset (Figure 6). These images were normalized and equalized.

2) Acquisition of the thermal images using an infrared camera (we have used the ThermaCAM E320 from FLIR Systems). The corresponding thermal images are shown in Figure 7.

3) Image Registration of the 2D MRI/CT image projection (Figure 6) with the corresponding thermal images (Figure 7). The registered images (according to the respective angles) are shown in Figure 8. This registration process involves the overlap of the thermographic pixels onto MRI/CT slices, on a slice per slice bases.

4) The 3D visualization is done using OpenGL library. The voxels on the outer surface of the 3D image show the thermal data while preserving all the MRI/CT morphological information. The 3D thermal images of the phantom are shown in Figure 9, from different views to perceive the 3D perspective.

Figure 6. Step (1) - 2D MRI projections created from the 3D MRI volume. The projections were created at 0º (front view), 90º, 180º, and 270º, respectively.

Finally, the 3D visualization, step (d) in Figure 2, is detailed at the next section (3-Results).
Figure 7. Step (2) - Thermal images at 0º (front view), 90º, 180º, and 270º, respectively.

Figure 8. Step (3) - Thermal image registration at 0º (front view), 90º, 180º, and 270º, respectively.

Figure 9. 3D thermal image visualization, showing different views and transparency of the head phantom.

In this case, since the phantom is hollow, there is no internal structure to be analyzed. This experiment was performed to validate the method.

The 3D thermal obtained with a volunteer is shown in Figure 10. In this figure it is possible to observe the internal and the external surface temperature. This model represents the new hybrid 3D model, showing both the inner MRI slices registered with the outer thermal surface.

The differential of this methodology is that the 3D model obtained consists in the fusion of two imaging methods: MRI or CT and thermographic images, in which the thermal images area representing a shell surrounding the MRI/CT slices.

Figure 10. 3D thermal image visualization of the head of an asymptomatic volunteer, showing both the inner information (MRI images/slices) and the outer information (thermograph images).

4. Discussion

A new image registration tool that combines two completely different medical imaging modalities: 2D surface thermal images and 3D MRI or CT image reconstruction, was presented. The result is a 3D thermal image visualization that contains the surface gradient temperature, measured by the IR cameras, and the anatomical internal information of the MRI or CT scanners.

As it is observed in Figures 9 and 10, the results obtained through the 3D THERMO methodology consist in the visualization of the internal structures together with the external temperature information or a 3D thermal shell surrounding (wrapping) the anatomical structure. Possible clinical applications for this methodology are diagnosis and monitoring of: peripheral vascular insufficiency, diabetic feet, tumors (e.g breast cancer), thyroid, sinusitis, fevers, headaches and migraines, and rheumatic diseases among other inflammatory process. Additionally, sports medicine and/or rehabilitation of athletes are other increasing areas for thermography. Since most of these injuries usually compromise not only bones but also muscles, ligaments and tendons.

More representative clinical studies need to be carried out to establish a correlation between surface thermal information to internal clinical findings. This methodology could potentially help in the diagnosis and monitoring of the dysfunctions mentioned above into a 3D scenario.

5. Conclusion

For the first time multimodal IR (thermal images) and MRI or CT data (image slices) were merged in order to generate a 3D structure, which incorporates both anatomical and physiological information at the same model.

The computational tool developed involves the 2D projection, the multimodal image registration (between thermal images and the MRI/CT slices), and generating a
fused (hybrid) 3D model, in which even the visualization of the several MRI/CT image slices (showing the internal structures) can be detailed observed.

This algorithm is fast and easy to use, which can be managed by medical staff, interacting and inspecting the object area under study.

3D THERMO involves 3D visualization, employing not only temperature (functional information) coming from the thermal images, but also MRI or CT images, which shows internal structures (anatomical information).

More specific clinical applications are being further investigated in order to expand the methodology, proving its efficiency through helping diagnosis and monitoring treatment.

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References


