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A novel fully automatic measurement of apparent breast volume from trunk surface mesh

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ABSTRACT

This paper presents a novel method for assessing apparent breast volume from trunk surface mesh without any manual intervention.

The proposed method requires a closed and smooth triangular mesh of the trunk. It comprises four main steps: automatic nipple localization, automatic breasts delineation, chest-wall interpolation and volume computation. The mean curvature is computed for each vertex using a quadratic fitting approach and used as an indicator to determine the convex fold of the breasts. The delineation is modeled as an ellipse in the frontal plane and all the vertices inside it are removed. The remaining ones are used to interpolate the chest wall with radial basis functions. The voxels inside the resulting mesh without breasts are then subtracted from the original voxelized volume to generate the breasts volume.

The validation is conducted on 30 adolescent female for each of which an MRI and a trunk surface (TS) acquisitions were available. Three breast volumes are considered: the anatomical volumes (AV) manually segmented on the MRI, the external volumes computed with the proposed method first in prone position (EVP) using the trunk mesh extracted from the MRI, and second, in standing position (EVS) using the TS's mesh. Significant correlations ($R>$ 0.77) are found between each two of the three volumes. AVs are much larger than both EVS and EPS. In fact, the manual segmentation using MRI slices allows for a direct visualization of the breast posterior delineation. Computed automatically, EVS and EPS are highly similar, indicating that the proposed method is robust to changes from prone to standing position. No significant difference between the regressions on the left and right breasts is noted.

Fully-automatic 3D breast volumetry from trunk surface mesh is feasible and provides measurements that are highly correlated to manual MRI volumetry and robust to changes in posture.

1. Introduction

Measuring breast volume is highly valuable in several clinical and research applications. For example, plastic surgeons rely on breast volumetry to plan their surgery and to optimize its outcome, whether it is a reconstruction of the breast after mastectomy or any other aesthetic breast intervention [1,2]. Also, breast volume asymmetry has proven to be a potential indicator of breast diseases in women [3]. Others have used breast volumetric in pattern making of brassieres [4]. In this paper, we are particularly interested in measuring breast volumes in female with adolescent idiopathic scoliosis (AIS).

AIS is a three dimensional deformity of the spine. It affects the general appearance of the trunk leaving patients concerned about their breasts asymmetry [5,6]. A reliable volumetric measurement would allow to objectively quantify breasts asymmetry. Consequently, it would help to evaluate breast asymmetry's prevalence in patients with scoliosis and its relationship with the spine and ribcage deformities. On top of that, having a reliable metric would allow taking into consideration this aesthetic aspect, much important in patients eyes, in surgical treatment planning.

Different methods for measuring breast volume are available starting with anthropomorphic methods based on simple distance measurements taken directly on the body surface [7]. Other methods consists either in measuring the liquid displacement after submerging the patients breasts in water [8] or in taking a 3D cast of the breast and then measuring its volume [9]. All these methods require a direct contact with the patients and it thus can be very intimidating, particularly for adolescent patients.

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Three-dimensional medical imaging offers a good alternative for breasts volume measurement without direct contact with the patients. Computed-tomography (CT) and magnetic resonance imaging (MRI) are two possible options [8–10]. They provide 3D volumes of the torso allowing for a 3D segmentation of the anatomic breast volumes. However, image acquisition in both modalities is performed with the patients lying down.

When a woman looks at herself in the mirror, she does not see the mammary gland but only the external shape of the breast. As we are interested in quantifying the breast volumes the way patients perceived it in the mirror, referred to as apparent volume, it is also important for the assessment to be done in the standing position. A good solution is provided by optical 3D scanning systems [9,11–15] that provide a three-dimensional mesh of the trunk surface in the standing position without contact nor radiation.

The main challenge with the trunk surface scans is the delimitation of the breast's dorsal boundary commonly called the "chest wall" and its contour on the mesh. Commercial systems, such as TC2 [16,17], 3dMD [11,18] and EM software [14], provide semi-automatic methods to measure breast volume from surface mesh. They all rely on a manual outlining of the breast. Then, an automatic interpolation of the chest wall is performed using either a flat plane or a Coon's patch [11,15,18]. However, since there is no clear boundary of the breast, even on a textured 3D model, outlining the breast on the mesh is a difficult [14] and highly subjective task. In fact, inter-operators differences of more than 50% of the breast volume have been reported [15].

In their paper, Koch et al. provide a comparison of the different methods used for breast volume measurement, with an emphasis on their validation process [15]. In most cases involving optical 3D scanning [9,15], the measurements are validated against breast volumes segmented manually on MRI slices. However, measurements based on MRI images reflect the volume of the mammary gland, the anatomic breast volume measurement as opposed to the apparent breast volume determined visually from the trunk surface in standing. Moreover, MRI acquisition is performed in prone position while trunk scanning is performed in the standing posture.

In this paper, a first fully-automated method for breast volume measurement from trunk surface mesh is proposed. It is also validated using an original validation scheme to compare not only anatomical and external breast volumes but also volumes in standing and prone positions.

2. Material

The proposed method for automatic breast volumetry requires a mesh of the trunk surface. In this study, we consider two different meshes: the first is acquired in the standing position using optical digitizers, the second is extracted from MRI volumes acquired in the prone position.

2.1. Trunk mesh in standing position

The whole trunk surface is acquired using a system of 4 optical Inspeck digitizers (Creaform, Levis, Canada). During the acquisition, the patient stands still in between the digitizers, with the arms slightly abducted on the sides. Each digitizer successively projects three phase-shifted fringe patterns on the trunk that are used to reconstruct one portion of the trunk in 3D. A forth image without fringes is used for texture mapping. The acquisition lasts less than 5 s.

The 4 polygonal surfaces are then preprocessed for denoising, registered and merged [19]. This acquisition and reconstruction system provides a closed and smooth triangular mesh of the whole trunk surface with an overall accuracy of 1.1 mm and a resolution of 3 mm [20].

2.2. Trunk mesh in prone position

The MRI acquisition of the trunk is performed with a 1.5 T system (Achieva XR, Philips Healthcare, Netherlands) using a dedicated 16-channel breast coil. The patient is lying prone with the arms raised overhead and the breasts hanging freely in the breast coil to optimize its natural contour. A 3D gradient-echo sequence is used with a repetition time of 7.6 ms, an echo time of 4.6 ms, a flip angle of 12°, an acquisition resolution of 1 mm$\times$ 1 mm$\times$ 2 mm and a reconstruction resolution of 1 mm$\times$ 1 mm $\times$ 1 mm. The field-of-view is adjusted on a subject by subject basis to cover the complete torso at the breast level.

From the MRI volumetric acquisition described previously, a closed and smooth triangular 3D mesh of the whole MRI volume is generated using ITK-SNAP 2.4.0 [21].

3. Proposed method

In this section, we describe the proposed breast volume measurement technique. Starting from a closed and smooth triangular mesh of the torso spanning the whole breasts volume (noted M_w), the method comprises four main steps: automatic localization of the nipples, automatic breasts delineation, chest-wall interpolation and volume computation. Each of these steps is described in the following subsections.

3.1. Automatic localization of the nipples

In presence of a textured mesh of the trunk, such as the one provided by the Inspeck system (Creaform, Levis, Canada), the 3D coordinates of the left and right nipples are automatically retrieved using the method proposed and validated in [22]. Briefly, the method consists first in identifying a region of interest (ROI) spanning the anterior part of the torso located under the armpits. Second, in this ROI, the curvature of the mesh is thresholded to 20% of its maximum value and the mean coordinates of the left and right candidate sets are used as approximate positions of the left and right nipples. Finally, a color analysis is applied in a circular region around the approximated nipple to refine its position. The method has been validated on a cohort of 26 female subjects. On average, the automatically detected nipples were 3.79($\pm$2.29) mm away from the manually selected nipples, which is smaller than the average nipple diameter (1.53($\pm$0.37) cm [23]) and in the same order of magnitude as the mesh resolution (3 mm [20]).

For the MRI generated meshes, the color information is absent. Since the breasts are hanging freely in a breast coil during MRI acquisition, we noticed that the torso sections that are the closest to the ground when the subject is lying prone, are in fact the nipples. Thus, for these meshes, we automatically identified the most anterior left and right points of the mesh as the left and right nipples respectively.

3.2. Breasts automatic delineation

The outline of the breast is difficult to visualize on a trunk mesh [4], even on a textured one [14]. To overcome this limitation, we considered the mesh curvature as an indicator to delineate the breasts, based on the assumption that the breast is a concave volume and its basis is a convex fold.

To compute the mesh curvature, we used a quadratic fitting approach [24]. The method starts with an estimation of the normal to each vertex by the angle-weighted average of the normals to its adjacent faces. Then, for each vertex, a local 3D frame is defined such as it is centered on the current vertex and the z-axis