Identification of Fiducial Points on 3D Torso Images Using Contrastive Learning

Sara Bouhali[1], Gregory P. Reece[2], Mia K. Markey[3,5] and Fatima A. Merchant[1,3,4]

[1]Department of Computer Science, University of Houston, Houston, TX, USA;
[2]Department of Plastic Surgery, The University of Texas MD Anderson Cancer Center, Houston, TX, USA;
[3]Department of Biomedical Engineering, The University of Texas at Austin, Austin, TX, USA;
[4]Department of Engineering Technology, University of Houston, Houston, TX, USA;
[5]Department of Imaging Physics, The University of Texas MD Anderson Cancer Center, Houston, TX, USA

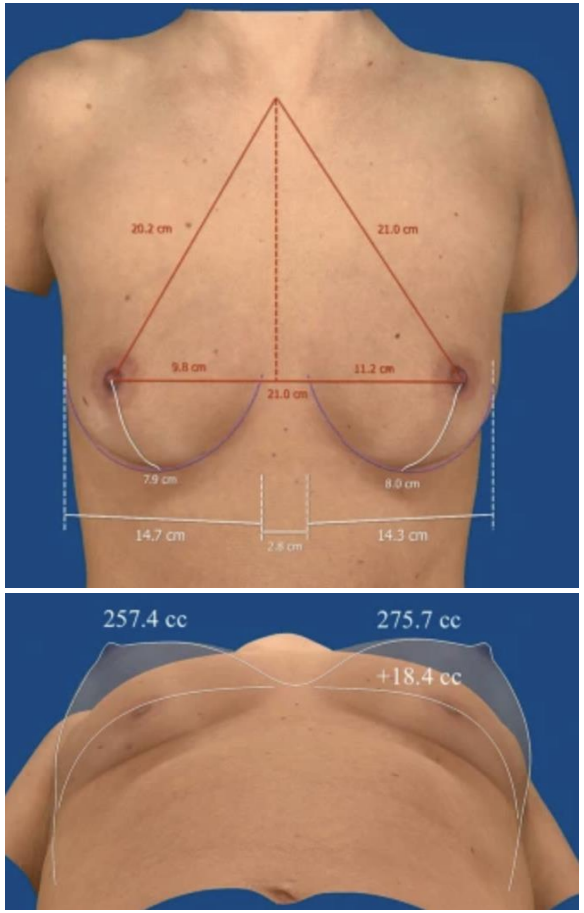
BMES
BIOMEDICAL ENGINEERING SOCIETY
2024 Annual Meeting
October 23-26, 2024

INTRODUCTION

- 3D imaging has become essential for quantitative breast morphometry, especially in monitoring changes in symmetry following reconstructive procedures.

- Breast morphometry from 3D photographs has been reported, however, several studies utilize manual identification of anatomical landmarks (fiducials), which is time-consuming and subject to operator bias.

- Using machine learning (ML) algorithms to automate the identification of fiducials would mitigate operator bias and yield reliable, objective measurements.



Breast Morphometry [1]

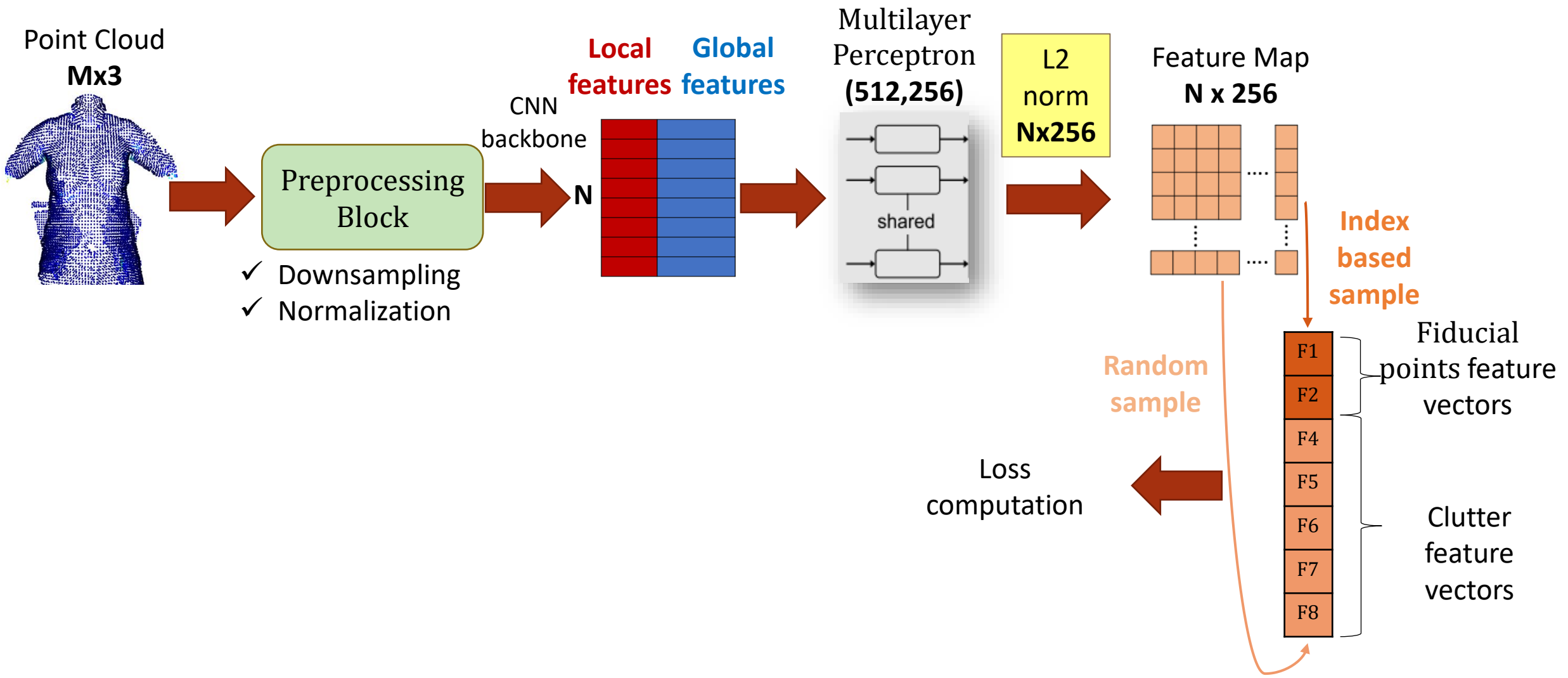
[1] Assaaeed S.K., et al. Evaluating 3D Simulation Accuracy for Breast Augmentation Outcomes: A Volumetric and Surface Contour A nalysis in Chinese Patients. Aesth Plast Surg (2024). https://doi.org/10.1007/s00266-024-04007-z

OBJECTIVE

- Automate the identification of fiducial points in 3D images using a machine learning framework.

METHODS

Pipeline of processing steps



METHODS

- Feature bank structure:

  Rows:

  – 2 fiducial points: Sternal Notch (SN), Umbilicus (U)

  – 20K Clutter points

  Columns:

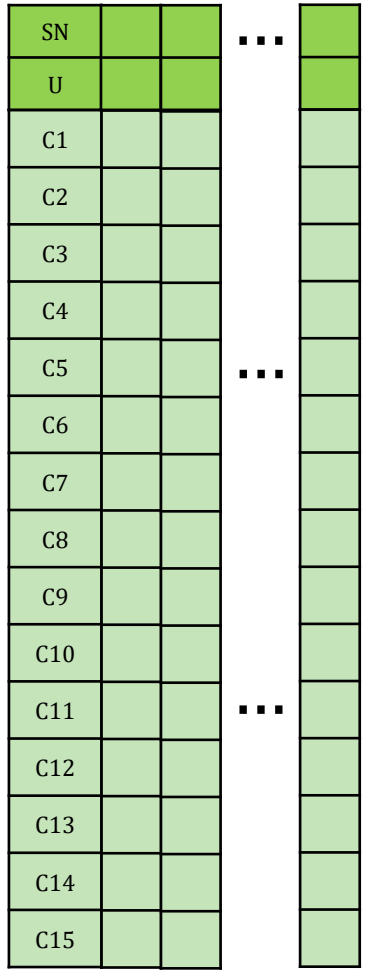
  – Features from feature vectors corresponding to each fiducial point and clutter point

- Feature bank optimization objectives:

  1. features of the same fiducial point are similar to each other;
  2. features of a fiducial point are distinct from features of different fiducial points;
  3. features of fiducial points are distinct from background clutter.

Feature Bank

20002 x 256



METHODS

- Contrastive Loss function
  - The objectives of the loss function are as follows:
    1. Minimize the distance within feature vectors of the same key point class.
    2. Maximize the distance between two feature vectors of different key point classes.
    3. Maximize the distance between key points set and all clutter feature vectors.

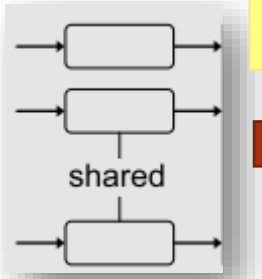
INFERENCE

3D Mesh
Mx3

Preprocessing Block

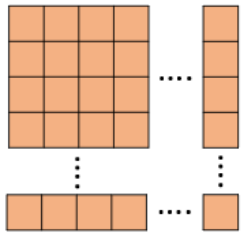
CNN backbone

Multilayer Perceptron **(512,256)**

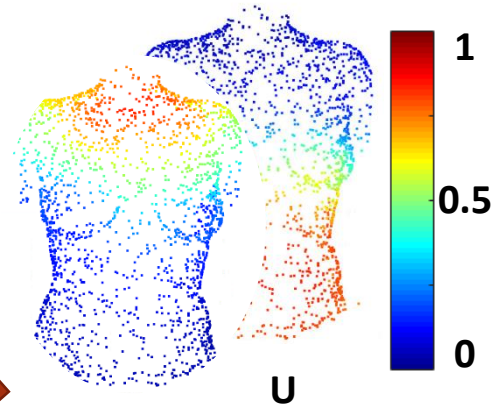


L2 norm **Nx256**

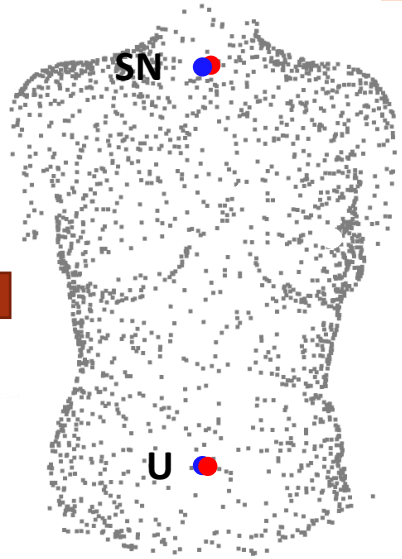
Feature Map **Nx256**

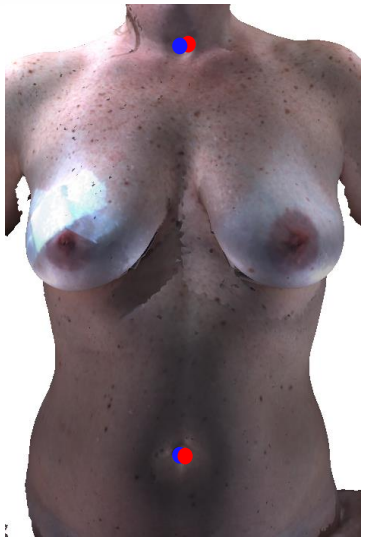


1D convolution with the key point bank **Nx2**



Argmax





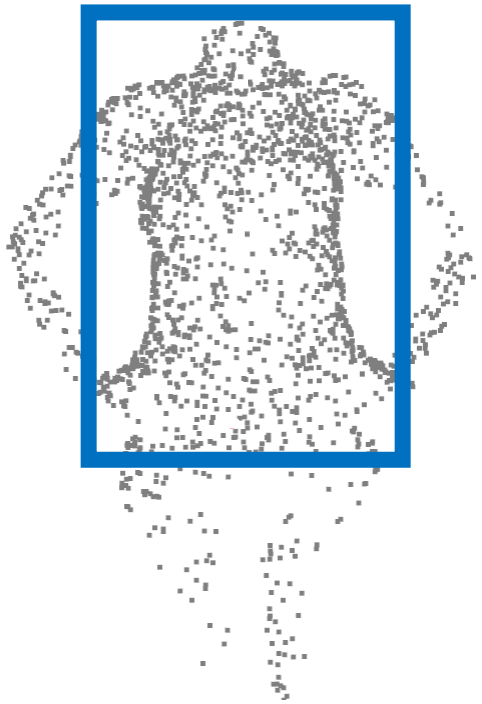
SN
U

key point Bank (2 x 256)

Blue: Target key points
Red: Predicted key points

DATASET

- Dataset
  - 273 3D images.
  - Preoperative and postoperative surface scans.
  - Cropped subject images.
  - All fiducial points (SN and U) are present.



Blue: cropping boundary

- Data Split

Training	70%	191 images
Validation	10%	27 images
Testing	20%	55 images

EXPERIMENTAL RESULTS

Evaluation protocol

- Percentage of correct key points formulation (PCK)
  - PCK considers a key point to be correct if its L_2 distance from the ground truth key point coordinates is less than *Radius*
  - *Radius* is a preset parameter to help determine the range of points surrounding a fiducial point.

Fiducial point	Diameter (mm)	Radius (mm)
Sternal Notch	40 [2]	20
Umbilicus	[20-25] [3], [4]	12.5

- Accuracy
  - We evaluate the accuracy per fiducial point (SN, U) by computing the corresponding PCK value.

[2] "Determination of sex from adult sternum by discriminant function analysis on autopsy sample of indian bengali population: A new approach. | IMSEAR." https://pesquisa.bvsalud.org/portal/resource/pt/sea-134635 (accessed Jun. 28, 2022).
[3] B. R. Baack, G. Anson, J. M. Nachbar, and D. J. White, "Umbilicoplasty: the construction of a new umbilicus and correction of umbilical stenosis without external scars," Plast Reconstr Surg, vol. 97, no. 1, pp. 227–232, Jan. 1996,
[4] S. B. Craig, M. S. Faller, and C. L. Puckett, "In search of the ideal female umbilicus," Plast Reconstr Surg, vol. 105, no. 1, pp. 389–392, 2000,

EXPERIMENTAL RESULTS

Approach benchmarking using torso images using accuracy and average distance results

- Kenig et al. [5] proposed a deep learning method in 2D breast surgery patients' frontal photographs, leveraging properties like grid structure that is not available in our 3D point clouds dataset.
- Kawale et al.'s [6] approach utilized surface curvature measurements on 3D meshes and color texture to identify fiducial points.

Approach	Data Format	Accuracy		Average prediction distance to GT [μ ± σ (mm)]	
		Sternal Notch (#)	**Umbilicus (#)**	**Sternal Notch (#)**	**Umbilicus (#)**
Kenig et al. [4]	2D image	**87%** (47)	NA	NA	NA
Kawale et al. [5]	3D mesh	36.36% (11)	63.64% (11)	22.4 ± 6.5 (11)	**11.5 ± 10.9** (11)
Proposed Method	3D mesh / point cloud	80.51% (55)	**71.01%** (55)	**13.66 ± 8.59** (55)	16.69 ± 7.92 (55)

Note: The number of images **(#)**, evaluated for each fiducial point is denoted within parentheses.
The Ground Truth **(GT)** is the manually annotated location of a fiducial point in images. **NA**: Not Applicable.

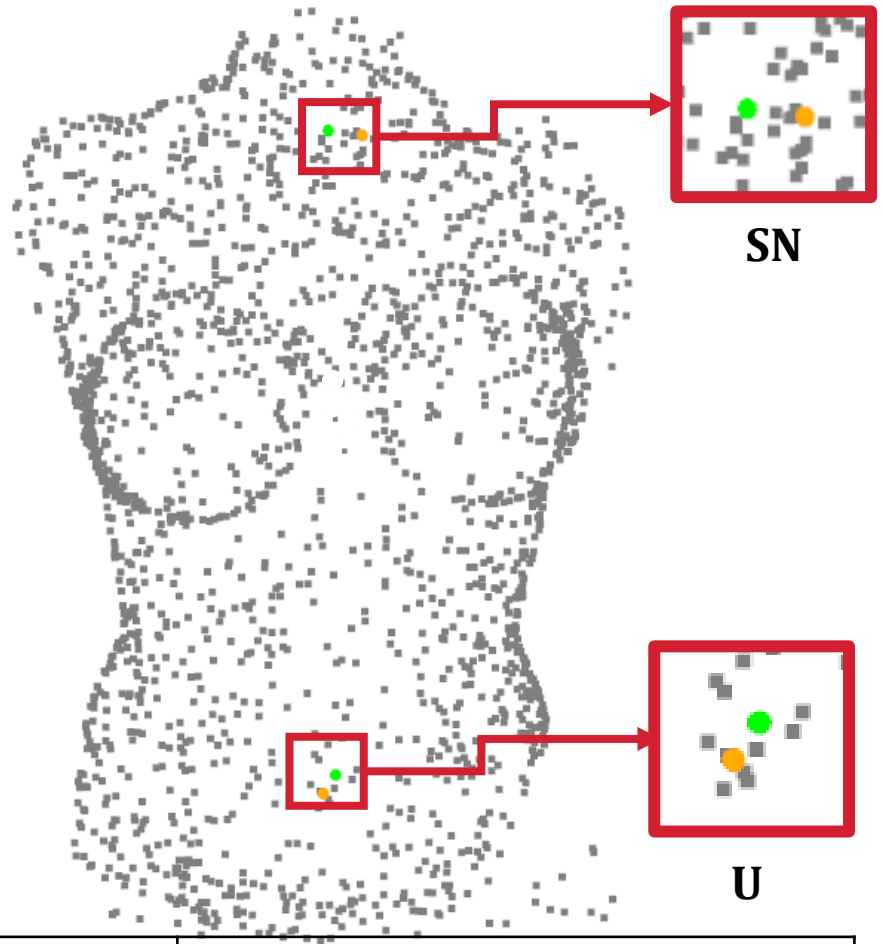
[5] N. Kenig, J. Monton Echeverria, and L. De la Ossa, "Identification of Key Breast Features Using a Neural Network: Applications of Machine Learning in the Clinical Setting of Plastic Surgery," Plast Reconstr Surg, vol. 153, no. 2, pp. 273E-280E, Feb. 2024,
[6] M. M. Kawale et al., "Automated Identification of Fiducial Points on 3D Torso Images," Biomed Eng Comput Biol, vol. 5, p. BECB.S11800, Jan. 2013

EXPERIMENTAL RESULTS

Testing Accuracy per BMI group

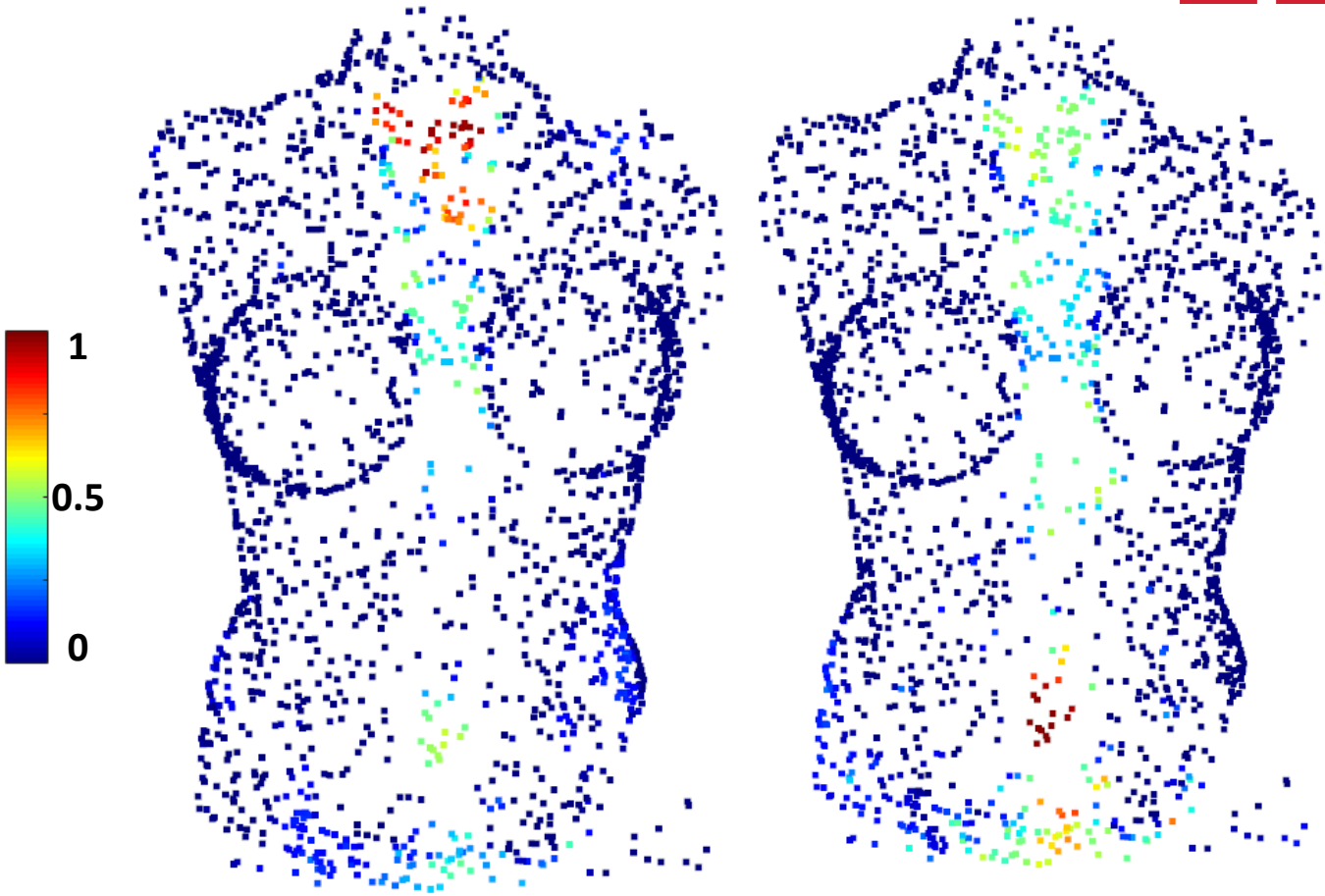
BMI group	Healthy [18.5,24.9]		Overweight [25,29.9]		Obese ≥ 30.0	
Number of images	17		12		24	
Proposed Method Accuracy	**Sternal Notch**	**Umbilicus**	**Sternal Notch**	**Umbilicus**	**Sternal Notch**	**Umbilicus**
	82.35%	70.82%	75.00%	**71.33%**	66.67%	69.12%

QUALITATIVE RESULTS



Patient #	**Orange**: Points predictions **Green**: Ground Truth
521	**Distance < Radius**

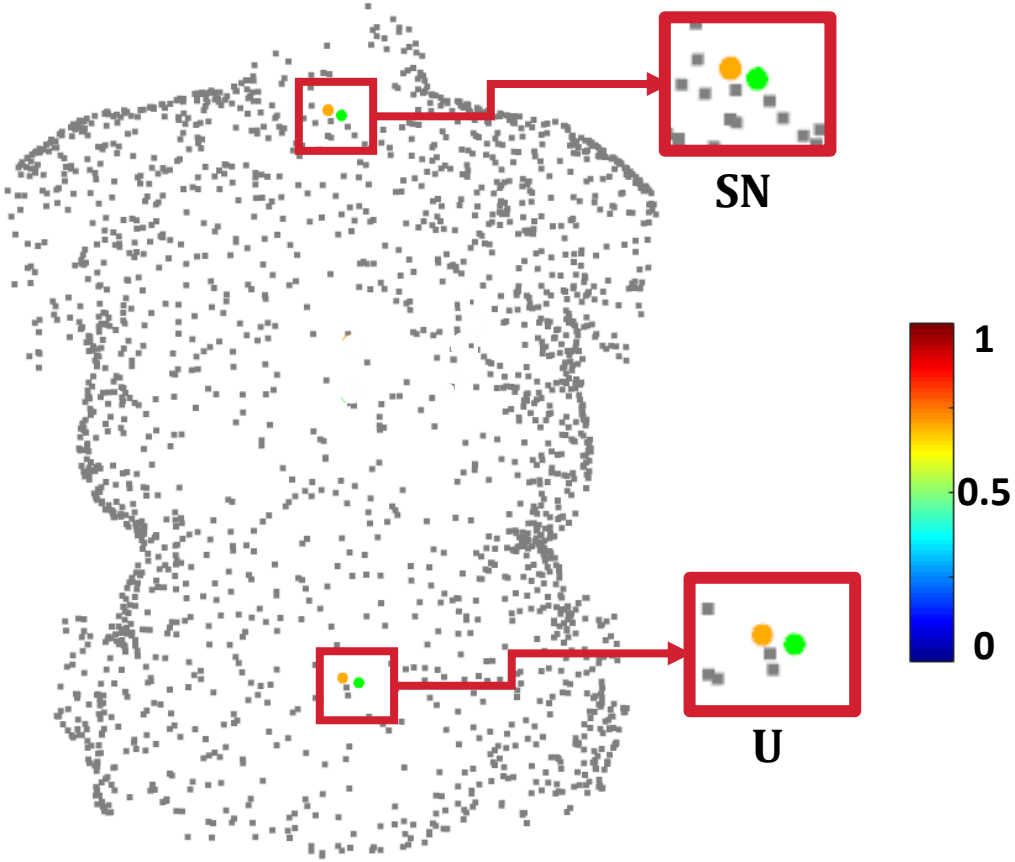
BMI = 21.38

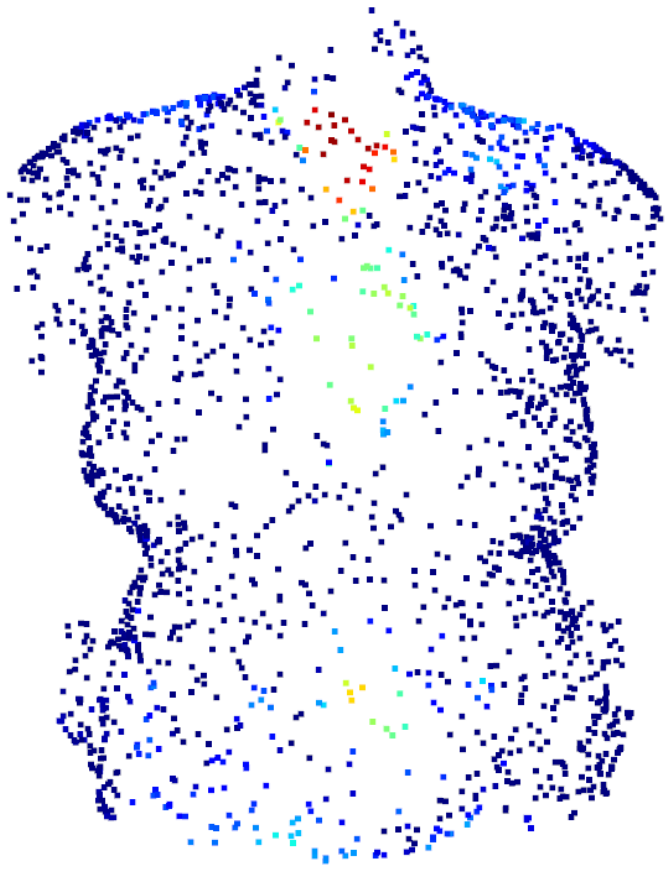


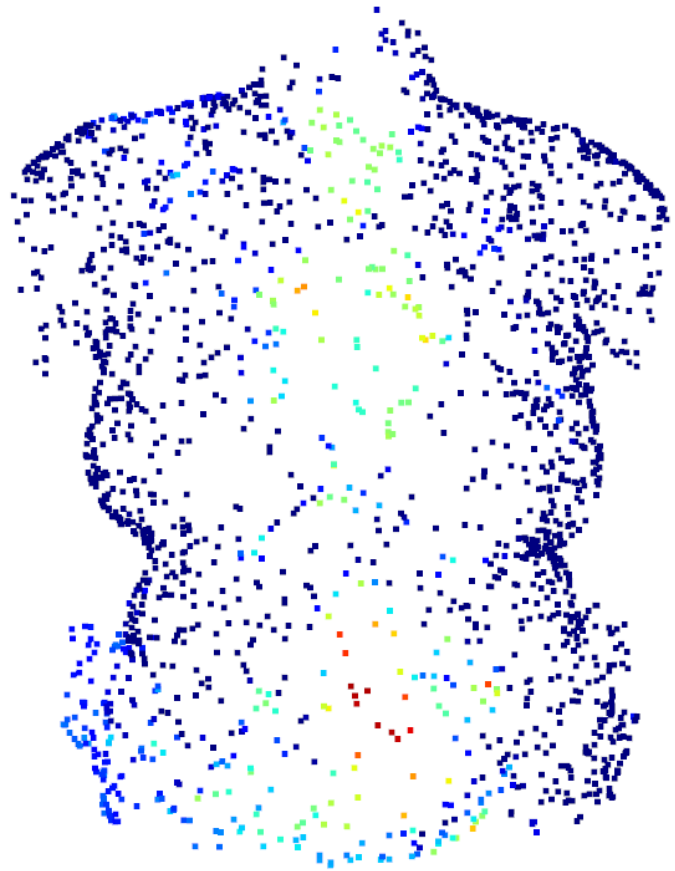
Sternal Notch Scoremap	Umbilicus Scoremap
True	True

QUALITATIVE RESULTS

BMI = 30



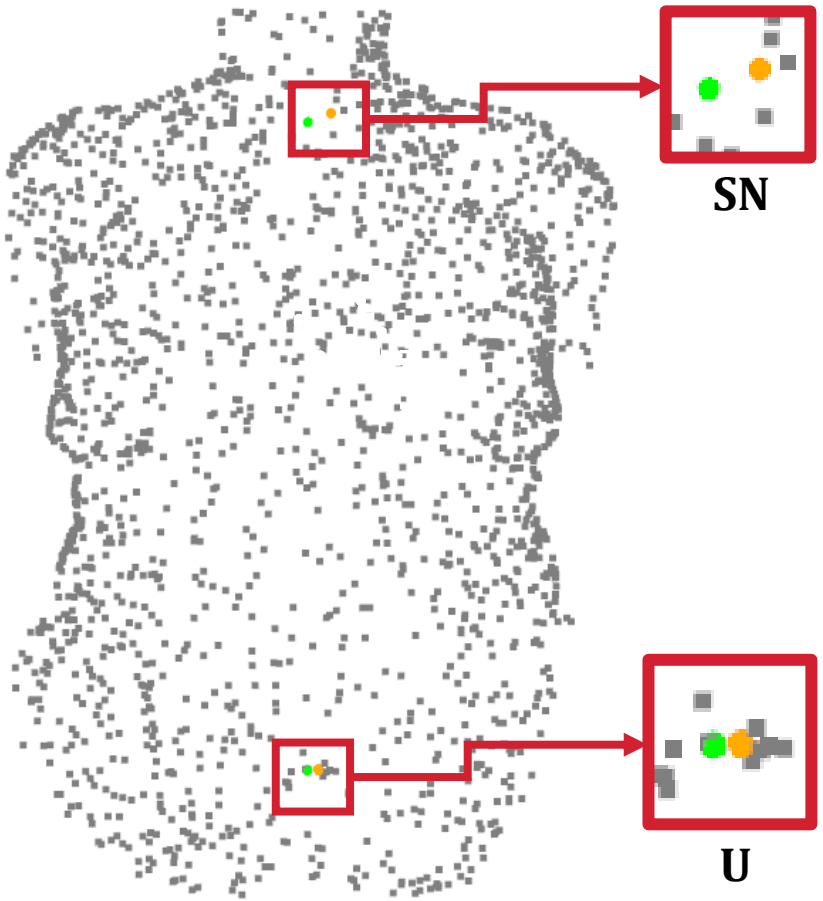




Patient #	**Orange**: Points predictions **Green**: Ground Truth
154	**Distance < Radius**

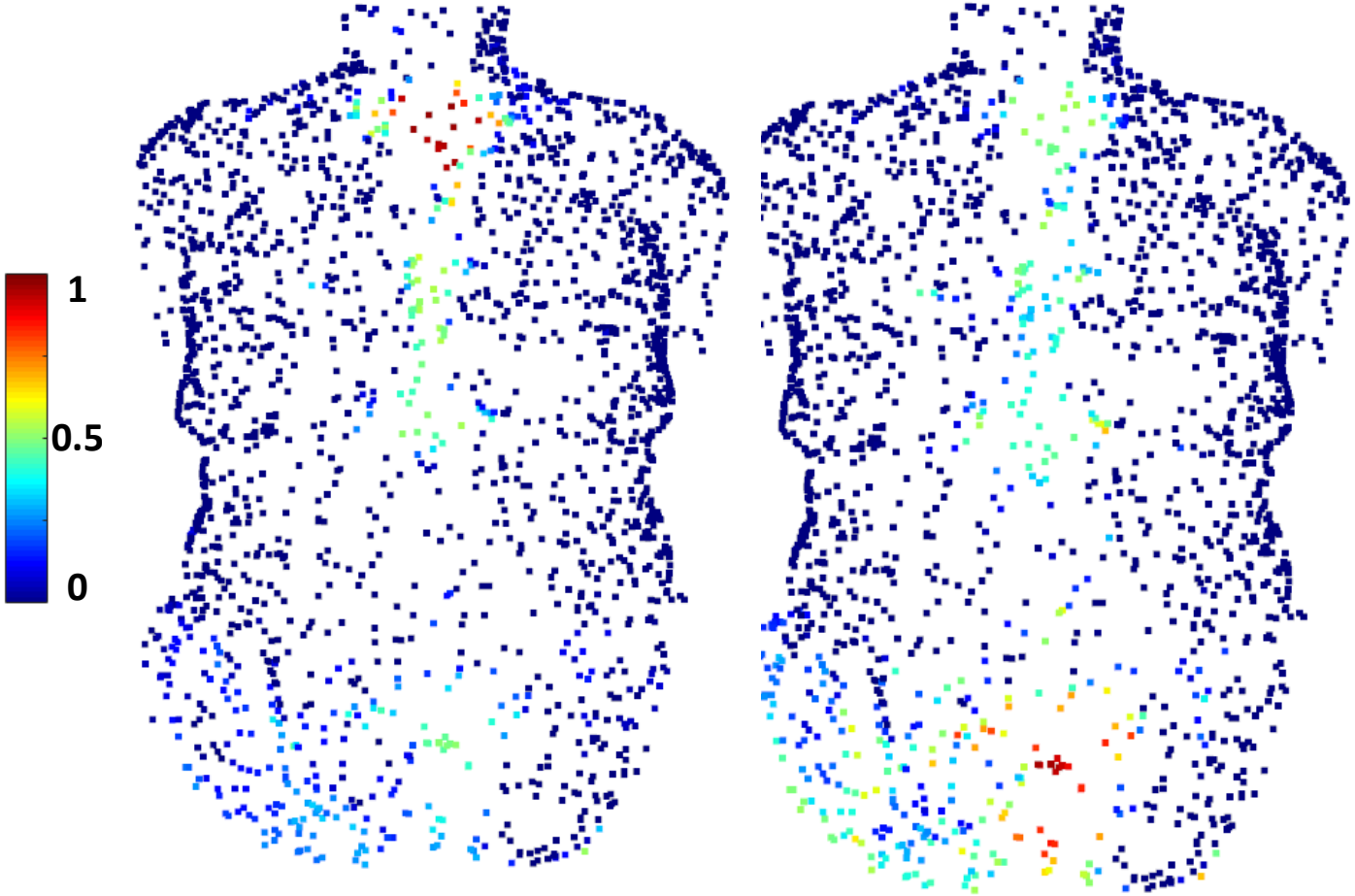
Sternal Notch Scoremap	Umbilicus Scoremap
True	True

QUALITATIVE RESULTS



Patient #	**Orange**: Points predictions **Green**: Ground Truth
578	**Distance < Radius**

BMI = 38.13



Sternal Notch Scoremap	Umbilicus Scoremap
True	True

CONCLUSION & FUTURE DIRECTIONS

- The proposed framework reliably identified the location of the fiducial points.
- The proposed framework can be extended to identify additional fiducial points on the torso.
- It can be integrated in various medical applications, such as the registration of 3D torso images from different clinical visits and the evaluation of breast symmetry in plastic surgery.

MULTIDISCIPLINARY BREAST RECONSTRUCTION RESEARCH PROGRAM

UNIVERSITY of HOUSTON

THE UNIVERSITY OF TEXAS MD Anderson Cancer Center
Making Cancer History®

TEXAS
The University of Texas at Austin

Sara Bouhali

Ph.D. Candidate
University of Houston
sbouhali@cougarnet.uh.edu

bitly

Find Us Online