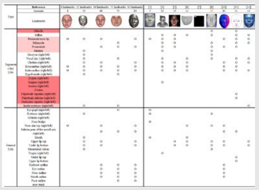
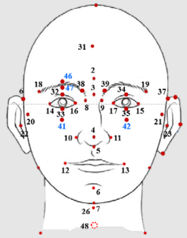
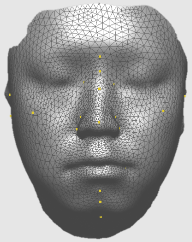
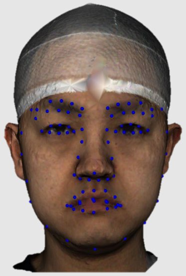
INDUSTRIAL AND MANAGEMENT ENGINEERING, POSTECH

Ergonomic Design Technology Lab

A Literature Review of Automatic Facial Landmark Detection Techniques

안면 측정 기준점 자동 탐색 기술의 문헌 조사



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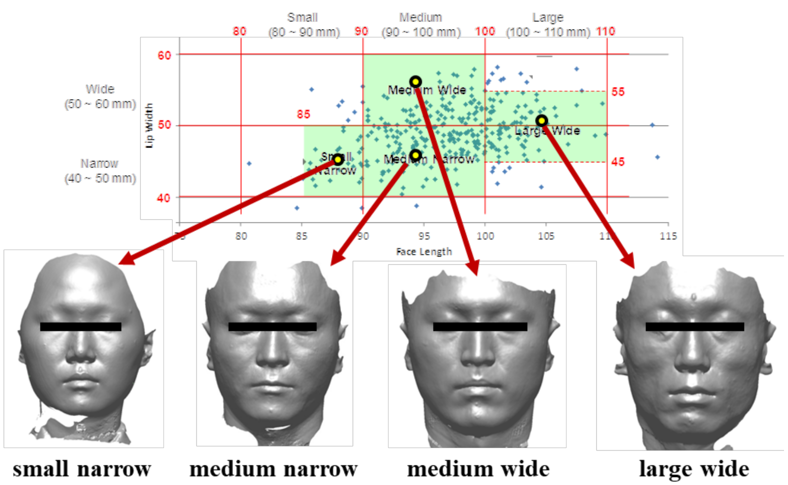
본 연구는 양산부산대학교병원 의생명융합연구소의 인큐베이팅 연구과제의 지원을 받아 수행된 결과입니다.

Contents

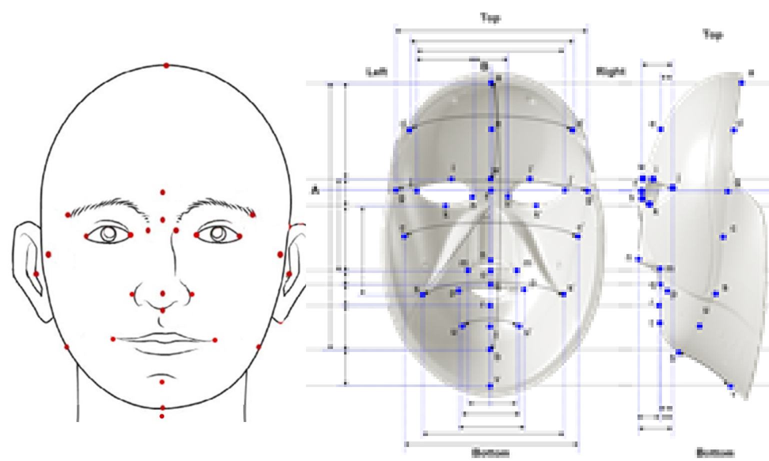
Introduction

- **Landmarks (LMs)** on 3D face scans have been used to measure facial dimensions, which can help analyze face features for ergonomic product designs.

Representative face model selection based on facial dimension measurement



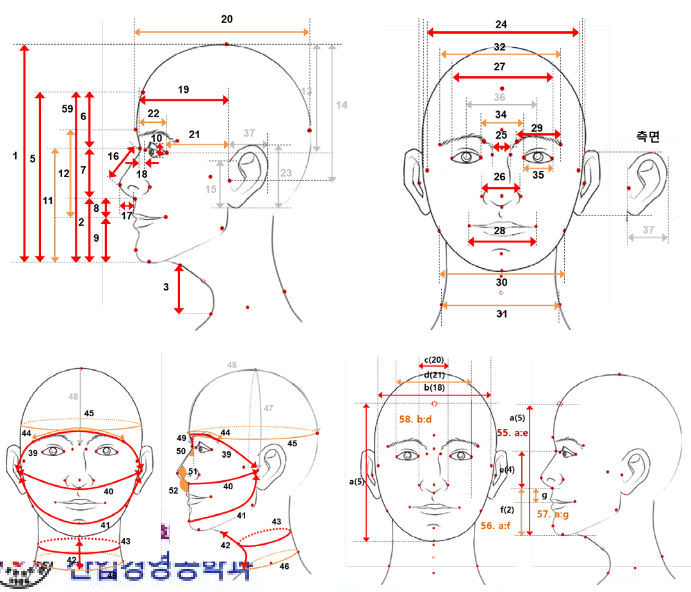
Product design based on facial dimension analysis



Research Motivation (1/2)

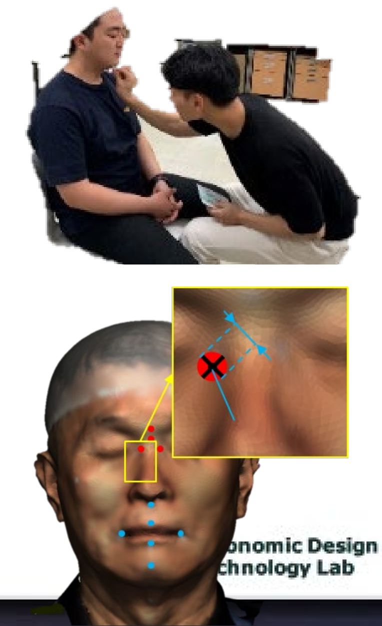
- **LMs** used in ergonomic studies are manually plotted on 3D face images by examiners, which is time and effort-demanding and leads to human biases when involving large datasets.
- **Palpation** on human face with stickers are conducted before 3D scanning for accurate localization later on 2D screen, which is in low efficiency.

Mask design analysis base on 58 facial dimensions extracted from 57 LMs



Manually localization of LMs by commercial SW

LM localization by palpation on human face



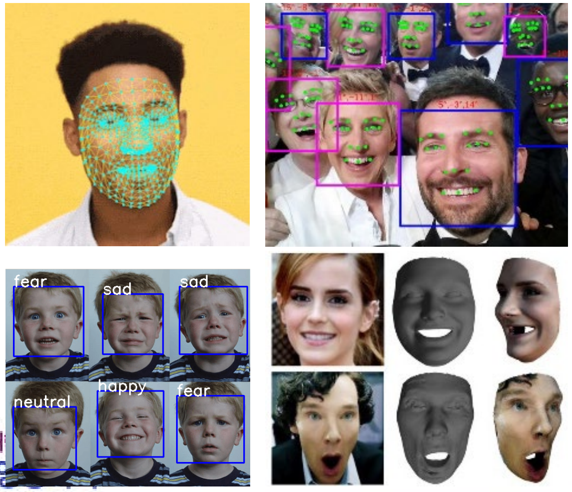
Research Motivation (2/2)

❑ Automatic LM detection technology has been developed for computer vision applications (e.g., face recognition & reconstruction) but less applied to the ergonomic field.

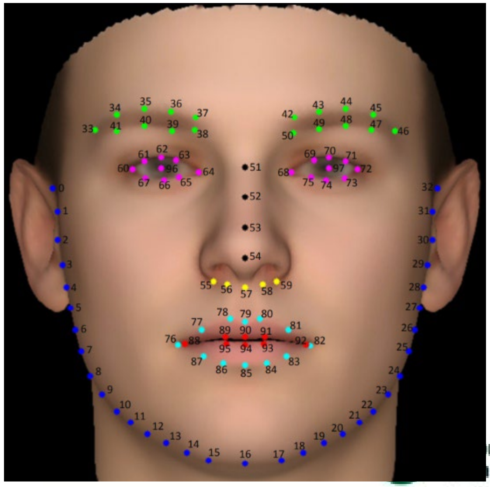
- ✓ The detection results provide insufficient LMs for anthropometry analysis.
- ✓ The effectiveness of detection results has not been verified in ergonomic field.

⇒ Necessary to develop an effective automatic 3D facial landmark detection method for ergonomic applications.

LM applications in computer vision



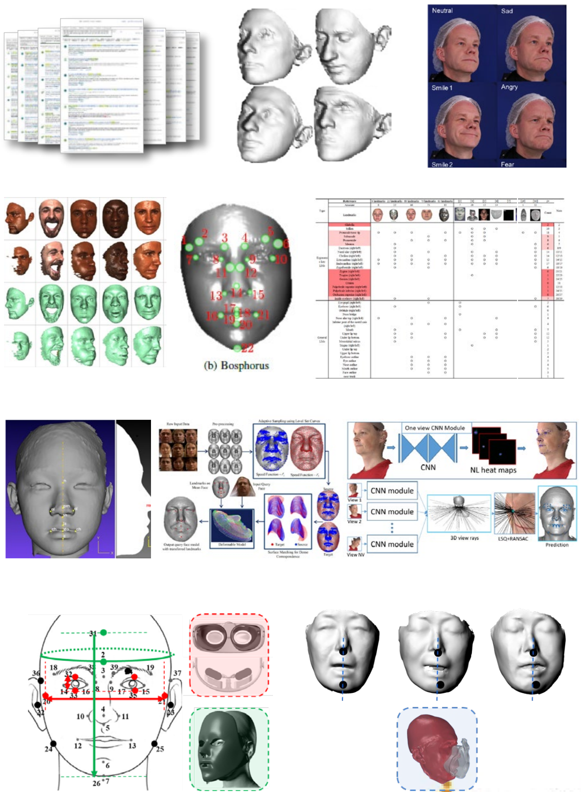
98 LM dataset



Objective of the Study

Systematic literature review for automatic 3D facial landmark detection techniques for ergonomic applications

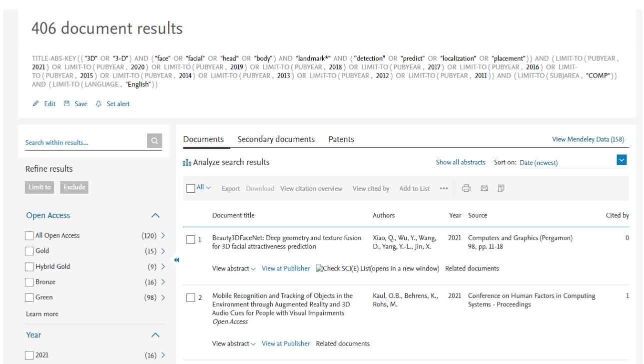
1. **The development of the automatic 3D facial LM detection**
   - Existing research direction
   - 3D face database
   - Landmarks
   - Landmark detection method
   - Evaluation & performance
2. **Discussion on the applicability and development needs for ergonomic applications**

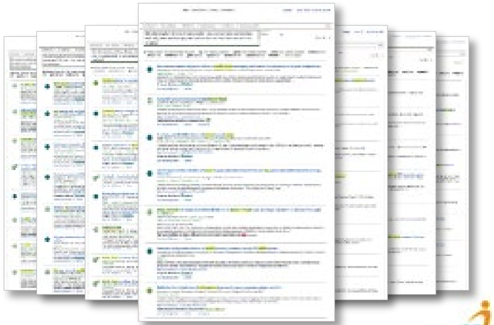


Literature Review: Search Method (1/3)

- Source: Scopus database
- Search Keyword
  - ✓ TITLE-ABS-KEY (("3D" OR "3-D") AND ("face" OR "facial" OR "head" OR "body") AND "landmark*" AND ("detection" OR "prediction" OR "localization" OR "placement"))
  - ✓ Limited to recent 10 years, engineering & computer science area
- Search results: 425 papers

Keywords combination search





Literature Review: Screening Process (2/3)

- A total of 30 papers were selected for final review.

S1. Keywords Combination Search

↓

S2. Title & Keyword Screening 1st

↓

S3. Abstract Screening 2nd

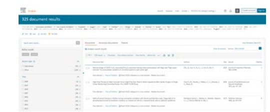
↓

S4. Relevance Evaluation

↓

S4. Paper Selection for Final Review

425 papers



↓

127 papers

↓

111 papers

↓ (-) From 2017

31 papers

↓ (+) Derived from reference / (-) irrelevant

30 papers

Literature Review: Paper List (3/3)

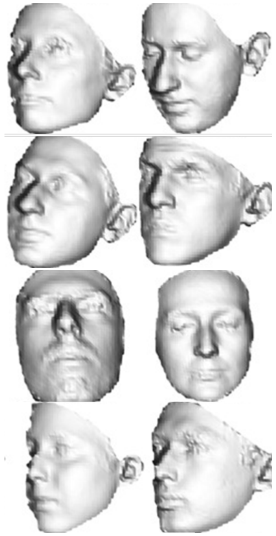
- After checking the full text of each of the screened papers, a total of 32 papers (high: 30 papers; medium: 2 papers) were lastly cited in the present study.

No.	Author(s)	Year	Title	Source	Relevancy
1	Wu and Ji	2018	Facial Landmark Detection: A Literature Survey	Computer Vision	M
2	Wang et al.	2018	Facial Feature Point Detection: A Comprehensive Survey	Neurocomputing	M
3	Pui et al.	2019	A Non-template Based Automatic Landmarking on 3D Face Data	Video and Image Processing	H
4	Huang et al.	2019	An Automated CNN-based 3D Anatomical Landmark Detection Method to Facilitate Surface-Based 3D Facial Shape Analysis	Lecture Notes in Computer Science	H
5	Bannister et al.	2020	Fully Automatic Landmarking of Dyndromic 3D Facial Surface Scans using 2D Images	Sensors	H
6	Terada et al.	2018	3D Facial Landmark Detection using Deep Convolutional Neural Networks	ICNC-FSKD	H
7	Deng et al.	2018	Facial Landmark Localization by Enhanced Convolutional Neural Network	Neurocomputing	H
8	Wang et al.	2019	Automatic Landmark Placement for Large 3D Facial Image Dataset	Big Data	H
9	Ridel et al.	2020	Automatic Landmarking as a Convenient Prerequisite for Geometric Morphometrics. Validation on Cone Beam Computed Tomography (CBCT)- based Shape Analysis of the Nasal Complex	Forensic Science International	X
10	Sun et al.	2019	Expression Robust 3D Facial Landmarking via Progressive Coarse-to-fine Tuning	ACM Transactions on Multimedia Computing	H
11	Jong et al.	2018	Ensemble Landmarking of 3D Facial Surface Scans	Scientific Reports	H
12	Conti et al.	2017	Landmarking-Based Unsupervised Clustering of Human Faces Manifesting Labio-Schisis Dysmorphisms	Informatica	X
13	Zhang et al.	2020	Deep 3D Facial Landmark Localization on position maps	Neurocomputing	H
14	Sullivan et al.	2019	Extending Convolutional Pose Machines for Facial Landmark Localization in 3D Point Clouds	ICCVW	H
15	Manal et al.	2019	Survey on the Approaches based Geometric Information for 3D Face Landmarks Detection	IET Image Processing	H
16	Agbolade et al.	2019	Homologous Multi-Points Warping: An Algorithm for Automatic 3D Facial Landmark	Automatic Control and Intelligent Systems	H
17	Abu et al.	2019	Automated Craniofacial Landmarks Detection on 3D Image Using Geometry Characteristics Information	Bioinformatics	H
18	Gao et al.	2019	Deep 3D Facial Landmark Detection on Position Maps	Intelligent Science and Big Data Engineering	H
19	Paulsen et al.	2019	Multi-view Consensus CNN for 3D Facial Landmark Placement	Computer Vision	H
20	Camgoz et al.	2015	Facial Landmark Localization in Depth Images using Supervised Ridge Descent	ICCVW	H
21	Krizaj et al.	2018	Localization of Facial Landmarks in Depth Images using Gated Multiple Ridge Descent	IWOBI	H
22	Cheng et al.	2018	3D Facial Landmark Localization Based on Two-Step Keypoint Detection	ICALIP	H
23	Vezzetti et al.	2018	3D Geometry-based Automatic Landmark Localization in Presence of Facial Occlusions	MTA	H
24	Gao et al.	2018	Expression Robust 3D Face Landmarking Using Thresholded Surface Normals	Pattern Recognition	H
25	Kai et al.	2017	Accurate landmarking from 3D facial scans by CNN and cascade regression	WMI	H
27	Xiao et al.	2018	Recurrent 3D-2D Dual Learning for Large-Pose Facial Landmark Detection	ICCV	H
28	Sghaier et al.	2017	Novel Technique for 3D Face Segmentation and Landmarking	GSCIT	H
29	Boukamcha et al.	2017	Automatic Landmark Detection and 3D Face Data Extraction	Computational Science	H
30	Wang et al.	2018	A Coarse-to-Fine Approach for 3D Facial Landmarking by Using Deep Feature Fusion	Symmetry	H
31	Gilani et al.	2015	Shape-based Automatic Detection of a Large Number of 3D Facial Landmarks	CVPR	H
32	Johnston and Chazal	2018	A Review of Image-based Automatic Facial Landmark Identification Techniques	Image and Video Processing	H
33	Shah et al.	2016	Automatic 3D Face Landmark Localization based on 3D VECTOR Field Analysis	IVCNZ	H
34	Liang et al.	2013	Improved Detection of Landmarks on 3D Human Face Data	IEEE EMBS	H

Existing Research Directions (1/2)

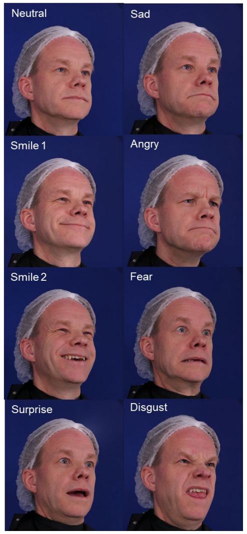
- Solve landmark detection **"in the wild"** by leveraging strengths of methods in different categories [1]
- In real-world scenarios, facial images are often acquired in uncontrolled conditions: 1) appearance variations (e.g., pose, expression, ethnic background, occlusions, without texture) and 2) environment variations (illumination)

Pose variation (Bosphorus DB)



[4, 21]

Expression variation (ERSC DB)

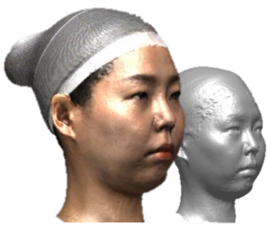


[3, 4, 10, 21, 23, 24]

Occlusion (Bosphorus DB)

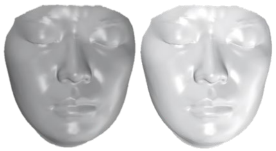
[4]

Texture (EDT DB)



[21, 23]

Illumination (EDT DB)



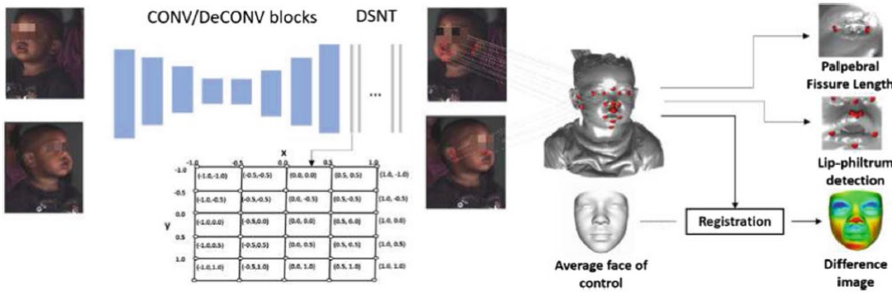
[31]

Existing Research Directions (2/2)

- Overcome the disadvantage of machine learning based methods that require large datasets
  - ✓ Low training complexity of 30-40 training samples [11]
  - ✓ Not large 30 training samples but involves human decision [8]
- Consider special application scenarios (e.g., facial deformities)
  - ✓ FASD (fetal alcohol spectrum disorder) with anatomical measurements demands [4]
  - ✓ 3D LM identification on subjects with genetic syndromes who have facial dysmorphia [5]

FASD identification visual examination

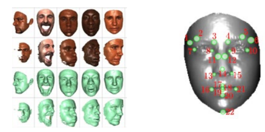
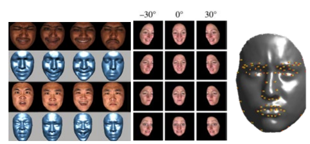
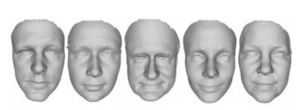
Automatic landmark detection for FASD



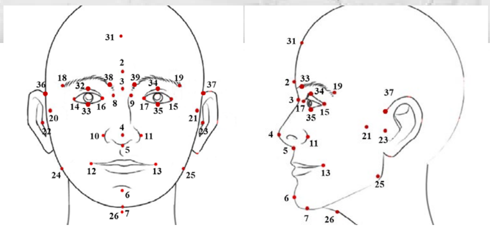
Huang et al.(2019)

3D Face Databases

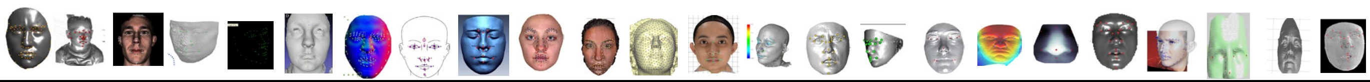
- The public 3D face scan database shows insufficiency for machine learning-based methods that require a large number of samples.

No.	Database	Features	Sample	Source	Accessibility
1	Bosphorus	▪ Images: 4666 3D faces ▪ Subj.: 105 ▪ Variability: expressions, poses, occlusions ▪ Landmark: 22		http://bosphorus.ee.boun.edu.tr	Free (only 2D image available)
2	FRGCv2	▪ Images: 4007 ▪ Subj.: 466 ▪ Variability: expressions ▪ Landmark: 8 ▪ UND: 1680, 537, rotation		https://cvrl.nd.edu/projects/data/#face-recognition-grand-challenge-frgc-v20-data-collection	Free
3	BU_3DFE	▪ Images: 2400 3D facial models ▪ Subj.: 100 ▪ Variability: expressions, angles (about ±45 ◦yaw angle) ▪ Landmark: 83		http://www.cs.binghamton.edu/~lijun/Research/3DFE/3DFE_Analysis.html	Commercial
4	BU_4DFE	▪ Images: 60600 3D face frames with 6 videos ▪ Variability: expressions			
5	FaceBase	▪ Images: 444 3D facial scan ▪ Subj: 369 (age: 1-75) ▪ Variability: genetic syndrome ▪ Landmark: 12		www.facebase.org	Free
6	DTU-3D	▪ Subj: 601 ▪ Landmark: 73		-	Not available
7	Stirling/ESRC	▪ Subj: 101 ▪ Variability: expression ▪ Landmark: 16		http://pics.stir.ac.uk/ESRC/index.htm	Free

Landmarks: Frequency of Detection (1/4)



- The detection for partial ergonomic key LMs was not sufficient.

Type	Reference	[3]	[4]	[5]	[6]	[7]	[8]	[10]	[11]	[12]	[13]/[18]	[14]	[16]	[17]	[19]	[20]	[21]	[22]	[23]	[24]	[25]	[27]	[28]	[29]	[30]	24		Note
	Amount	7	20	12	14	68	23	83	21	13	68	78	16	10	73/83	24	22/8	7	13	7	22	21	5	1	22			
	Landmarks																									Count	Frequency	
Ergonomic key LMs	Glabella						o		o																	2	8%	2
	Sellion		o	o	o		o		o	o			o	o					o	o						10	42%	3
	Pronasale/nose tip	o	o	o				o	o	o	o		o	o		o	o	o	o	o	o		o	o	o	18	75%	4
	Subnasale		o	o			o		o	o			o	o	o					o						9	38%	5
	Promentale		o	o			o	o	o		o		o		o											8	33%	6
	Menton		o				o									o	o				o				o	6	25%	7
	Dacryon (right/left)						o								o	o	o				o				o	6	25%	8/9
	Nasal alar (right/left)		o		o		o		o	o			o	o	o	o	o		o	o	o				o	14	58%	10/11
	Cheilion (right/left)		o	o	o			o	o	o	o		o	o		o	o	o			o				o	14	58%	12/13
	Ectocanthus (right/left)		o	o	o			o	o		o		o		o	o	o	o	o		o		o		o	15	63%	14/15
	Endocanthus (right/left)		o	o	o			o	o	o	o		o		o	o	o	o	o	o	o		o		o	17	71%	16/17
	Zygofrontale (right/left)														o	o	o		o		o				o	6	25%	18/19
	Zygion (right/left)																									0	0%	20/21
	Tragion (right/left)		o																							1	4%	22/23
	Gonion (right/left)														o											1	4%	24/25
	Crinion																									0	0%	31
	Palpebrale superius (right/left)								o																	1	4%	32/33
	Palpebrale inferius (right/left)								o																	1	4%	34/35
	Otobasion superius (right/left)																									0	0%	36/37
	Inside eyebrow (right/left)									o					o	o	o		o		o				o	7	29%	38/39
General LMs	Eye/pupil (right/left)	o													o											2	8%	
	Eyebrow (right/left)	o					o									o	o				o				o	6	25%	
	Orbitale (right/left)																									0	0%	
	Nose bridge	o																								1	4%	
	Nose alar top (right/left)				o		o	o			o															4	17%	
	Inferior pont of the nostril axis (right/left)							o	o		o				o											4	17%	
	Mouth	o			o									o		o	o				o				o	7	29%	
	Upper lip top			o	o		o	o		o	o		o	o		o	o				o				o	12	50%	
	Under lip bottom			o	o		o	o		o	o		o	o		o	o				o				o	12	50%	
	Mentolabial sulcus						o									o	o				o				o	5	21%	
	Tragus (right/left)		o																							1	4%	
	Under lip top								o							o										2	8%	
	Upper lip bottom								o							o										2	8%	
	Eyebrow outline							o				o			o							o				4	17%	
	Eye outline							o			o	o			o							o				5	21%	
	Nose outline							o			o	o			o											4	17%	
	Mouth outline							o			o	o			o							o				5	21%	
	Face outline											o			o							o				3	13%	
	nose trunk																					o				1	4%	

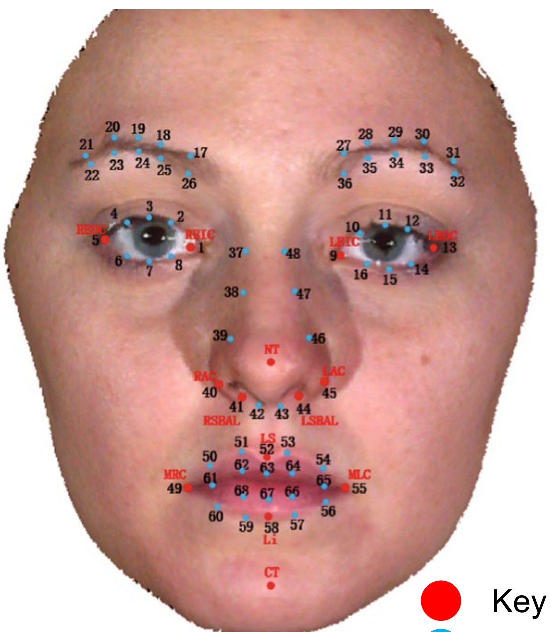
LM in low frequency (10-50%)

LM almost missed (<10%)

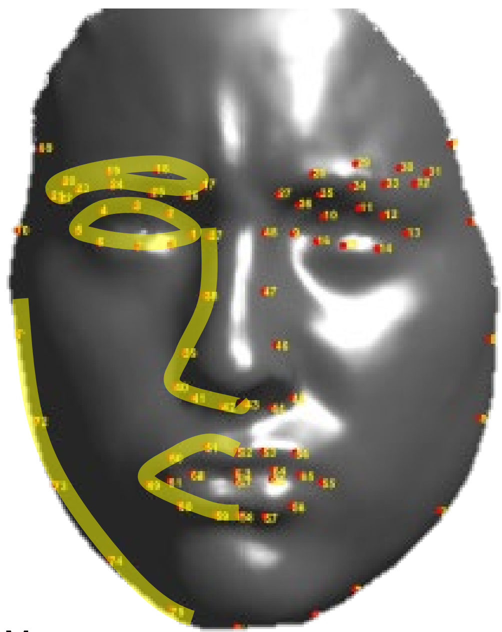
Interpolated Landmarks (2/4)

- LMs were detected in the perspective of facial key points and interpolated landmarks.
- Interpolated landmarks which represent the outline or the trunk of face parts (eyebrow, eye, nose, mouth, face) were frequently detected.

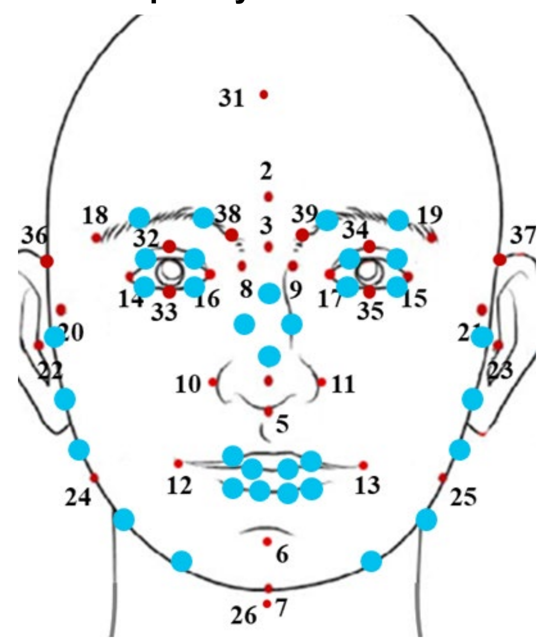
68 points



Interpolated LMs on outlines



Frequently detected LMs



Key LMs
Interpolated LMs

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산업경영공학과

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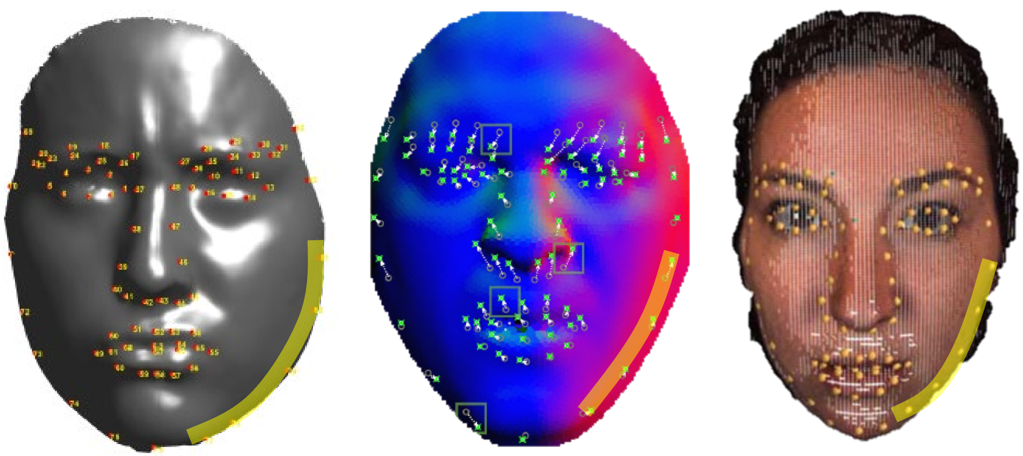
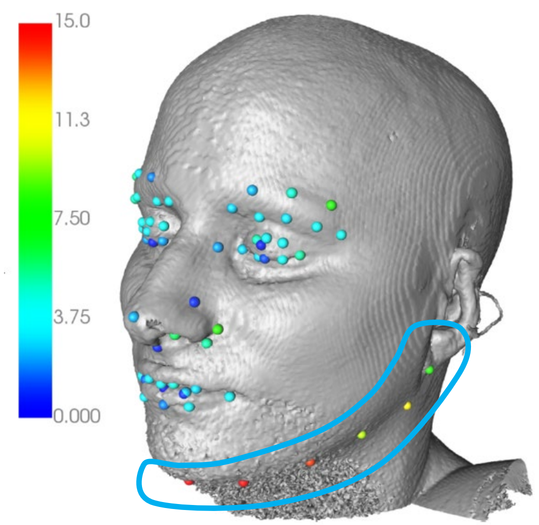
Interpolated Landmarks on Face Outline (3/4)

- The detection accuracy of interpolated LMs on the face outline is still challenging.

Outline LMs detected in less accuracy



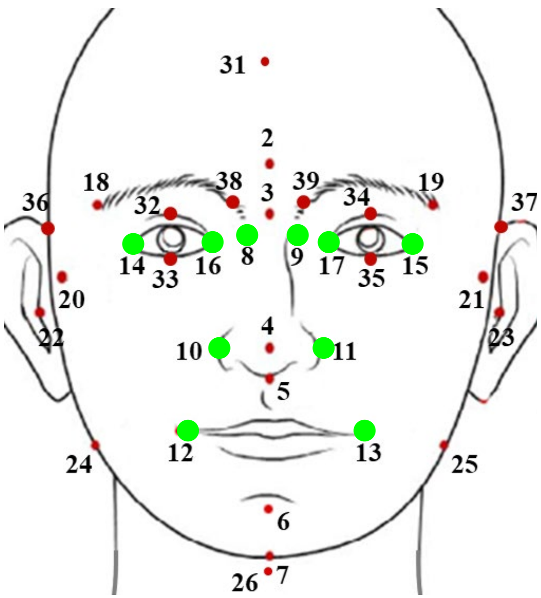
True location of outline LMs



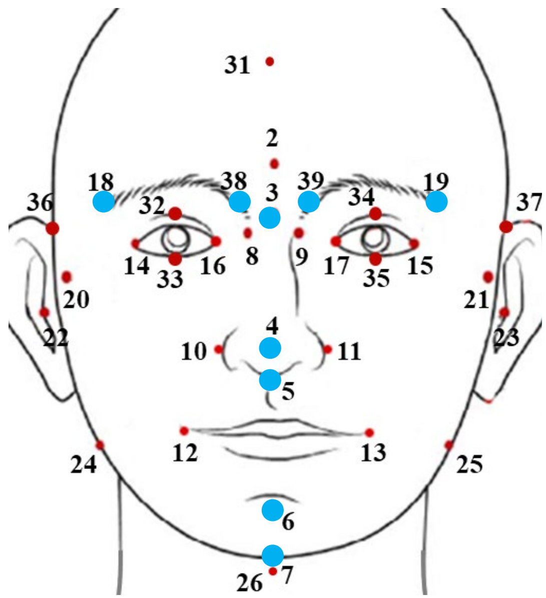
Ergonomic Key LMs (4/4)

- Among the ergonomic key LMs, 10 LMs were detected in high frequency, 9 LMs were detected in low frequency, 14 LMs were almost missed detection.

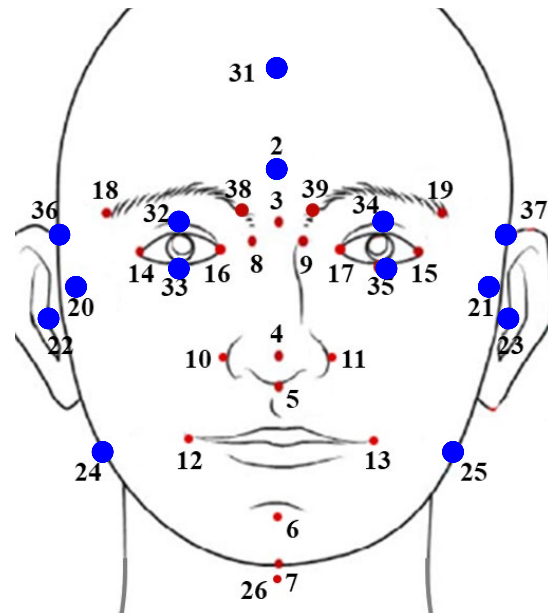
LMs detected in high frequency



LMs detected in low frequency



LMs almost missed detection

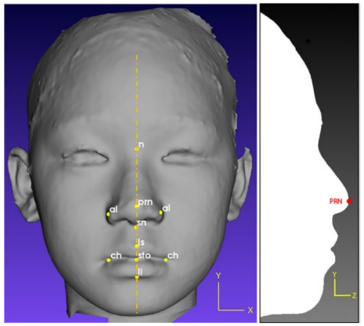


3D Landmark Detection Methods (1/5)

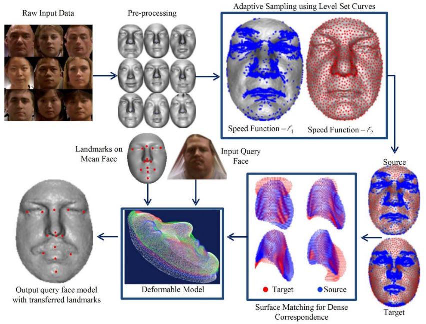
- 3D landmark detection was organized into (1) geometry-based method, (2) template-based method, (3) AI-based method

No.	Paper	Category
17	Abu et al. (2019)	GS
23	Vezzetti et al. (2018)	GS
24	Gao et al. (2018)	GS
28	Sghaier et al. (2017)	GS
29	Boukamcha et al. (2017)	GS
33	Shah et al. (2016)	GS
16	Agbolade et al. (2019)	TF
31	Gilani et al. (2015)	TF
34	Liang et al. (2013)	TF
3	Pui et al. (2019)	AI
4	Huang et al. (2019)	AI
5	Bannister et al. (2020)	AI
6	Terada et al. (2018)	AI
7	Deng et al. (2018)	AI
8	Wang et al. (2019)	AI
10	Sun et al. (2019)	AI
11	Jong et al. (2018)	AI
13 (18)	Zhang et al. (2020)	AI
14	Sullivan et al. (2019)	AI
18 (13)	Gao et al. (2019)	AI
19	Paulsen et al. (2019)	AI
20 (21)	Camgoz et al. (2015)	AI
21 (20)	Krizaj et al. (2018)	AI
22	Cheng et al. (2018)	AI
25	Kai et al. (2017)	AI
27	Xiao et al. (2018)	AI
30	Wang et al. (2018)	AI
1	Wu and Ji (2018)	LR
2	Wang et al. (2018)	LR
15	Manal et al. (2019)	LR
32	Johnston and Chazal. (2018)	LR

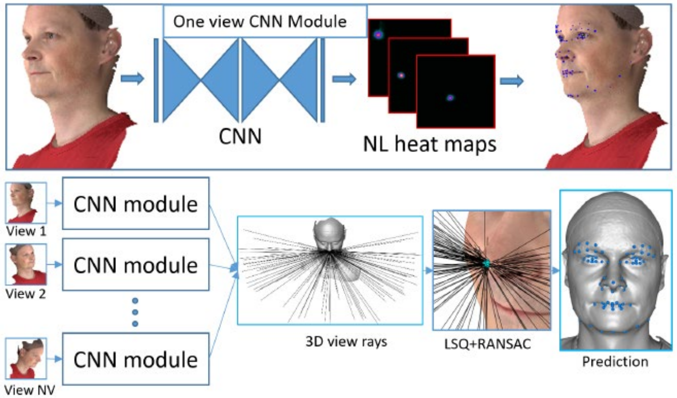
(1) Geometry-based method



(2) Template-based method



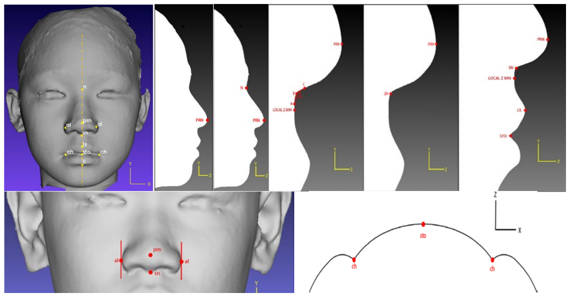
(3) AI-based method



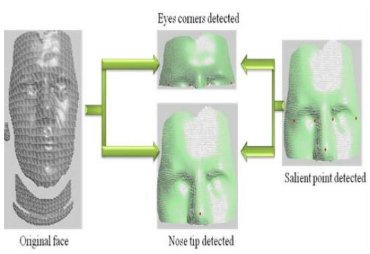
Geometrical Shape-based Method (2/5)

- Identify prominent LMs through a coarse to fine process by extracted **geometry characteristics** such as gaussian, mean, principal curvatures, shape index, curvedness, surface normal, and 3D vector fields.

Curvature

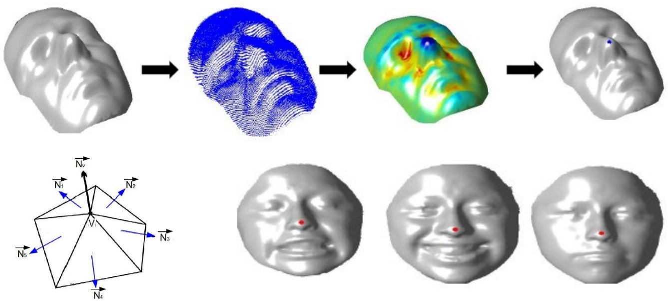


Abu et al. (2019)



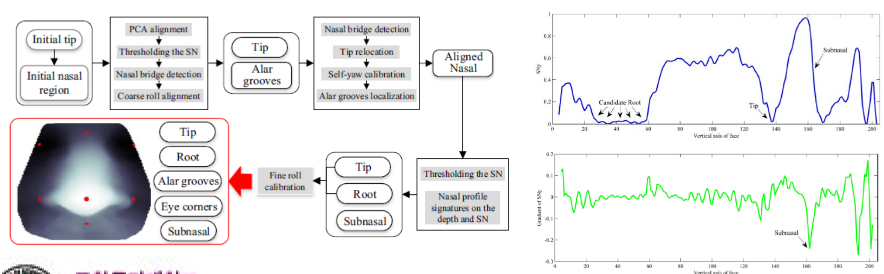
Sghaier et al. (2017)

3D vector field analysis



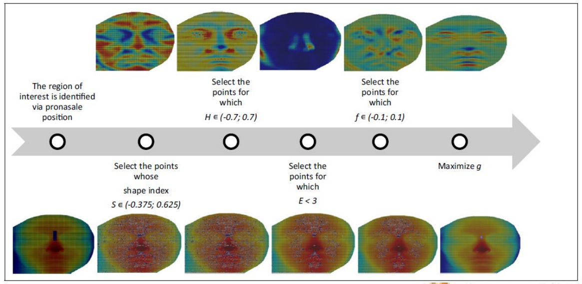
Shah et al. (2016)

Thresholded surface normal



Gao and Evans (2018)

Threshold geometrical descriptors
(e.g., point-by-point derivatives and curvatures)



Vezzetti et al. (2018)

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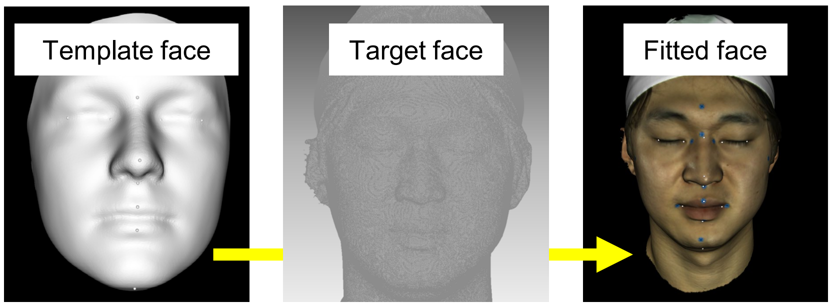
Template-fitting-based Method (3/5)

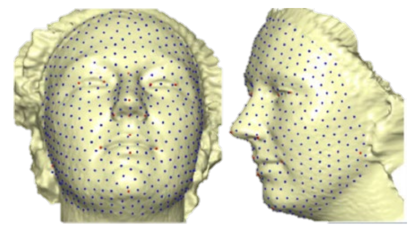
- Identify LMs through a initialization to fitting process through a template face with pre-defined LMs.

Algorithm for template-fitting:
NICP (non-rigid iterative closest point)

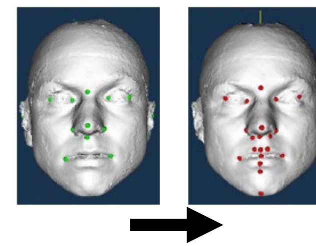


(deform the template mesh to match the morphology of the target mesh)

Fitting base on landmarks

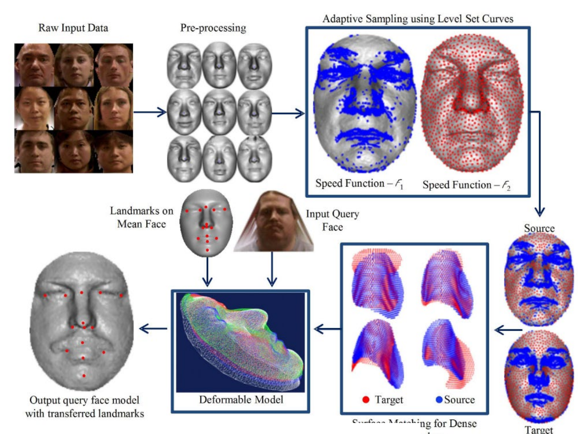


Agbolade et al. (2019)



Liang et al. (2013)

Fitting base on regions of point cloud

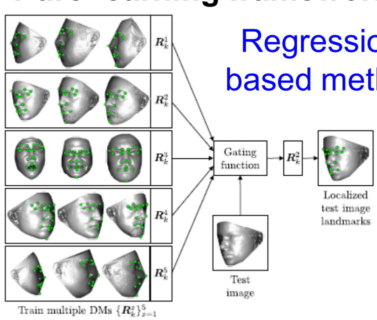


Gilani et al. (2015)

AI-technique-based Method (4/5)

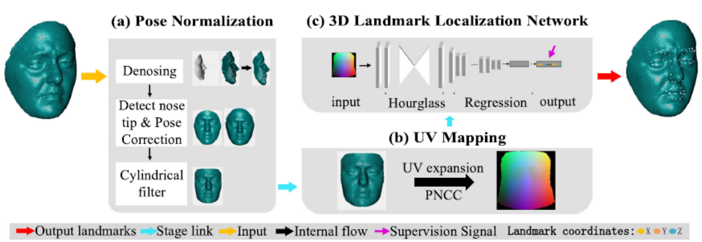
- Identify LMs by two broad frameworks: 1) pure-learning framework, and 2) hybrid framework.
  - ✓ Pure-learning framework: direct feature extraction on 3D data
  - ✓ Hybrid framework: combine with 2D image and projection model
- Various algorithms such as holistic, constrained local model (CLM), regression-based and deep learning based methods were applied.

Pure-learning framework



Regression-based method

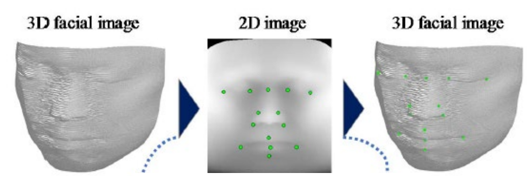
Krizaj et al. (2018)



Regression-based method

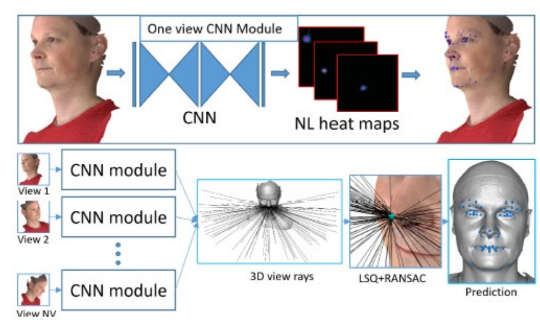
Zhang et al. (2020)

Hybrid framework



Deep learning based method (CNN)

Terada et al. (2018)



Deep learning based method (CNN)

Paulsen et al. (2019)

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Advantages and disadvantages (5/5)

- Advantages and disadvantages were organized as a reference for future automatic LM detection development.

Method	Advantages	Disadvantages
Geometrical shape-based method	▪ Not require any training ▪ Not rely on any particular model ▪ Efficient ▪ High accuracy	▪ Limited to landmarks with prominent geometric features (e.g., nose tip and eye corner)
Template-fitting-based method	▪ Fast ▪ Not limit to LMs (can detect any number or location of pre-defined LMs)	▪ Need initialization
AI-based method	▪ Solve landmark detection problems "in-the-wild"	▪ Need a certain amount of labelled data

Evaluation Criteria

- Conduct **relative evaluation** on accuracy and efficiency in **specific scope**
  - ✓ Dataset dimension
    - ➢ The amount of data
    - ➢ Features: expression, occlusion, pose, illumination, deformity
  - ✓ Landmark dimension: amount and type
  - ✓ Specifications of the PC

	Accuracy	Efficiency
Method	Comparing the detected LM locations with the ground truth LM locations	Comparing the computational cost
Measure	▪ Mean error of each landmark of all subjects ▪ Overall mean error ▪ RMSE (root mean square error) ▪ Ratio within a specified error range (e.g., within 5 mm and 10 mm)	▪ Training time ▪ Detection time

Performance

- The performance of LM detection methods on three most popular databases was roughly identified for further evaluation.

No.	Database	Features	Detected LMs	Mean error	Reference
1	Bosphorus	▪ Images: 4666 3D faces ▪ Subj.: 105 ▪ Variability: expressions, poses, occlusions ▪ Landmark: 22	▪ 7 LMs ▪ 8 LMs ▪ 10 LMs ▪ 22 LMs ▪ 83 LMs (manually extracted)	▪ 0.8 - 1.5 mm ▪ 2.7 - 7.2 mm ▪ 2.4 - 5.2 mm ▪ 2.1 - 6.0 mm ▪ 6.98 $\pm$ 3.94 mm (all)	[24] [23] [21] [25] [10]
2	FRGCv2	▪ Images: 4007 ▪ Subj.: 466 ▪ Variability: expressions ▪ Landmark: 8 ▪ UND: 1680, 537, rotation	▪ 7 LMs ▪ 7 LMs ▪ 10 LMs (FRGC+UND) ▪ 14 LMs	▪ 2.9 - 3.7 mm ▪ 1.2 - 6.9 mm ▪ 3.1 - 4.8 mm ▪ 2.66 $\pm$ 1.89 mm (all)	[22] [24] [21] [13]
3	BU_3DFE	▪ Images: 2400 3D facial models ▪ Subj.: 100 ▪ Variability: expressions, angles (about ±45 ◦yaw angle) ▪ Landmark: 83	▪ 4 LMs ▪ 7 LMs ▪ 11 LMs ▪ 14 LMs ▪ 14 LMs	▪ 3.3 - 4.9 mm ▪ 4.2 – 17.2 mm ▪ 1.8 – 3.0 mm ▪ 2.6 - 4.7 mm ▪ 1.5 – 2.8 mm	[24] [3] [19] [10] [13]

Discussion (1/4)

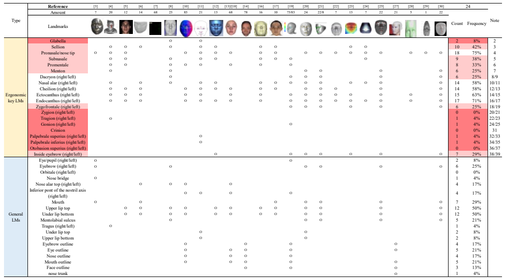
❑ 3D landmark detection techniques were organized in terms of data source, landmark, method, evaluation criteria, and evaluation performance.

⇒ Contribute to the development of automatic 3D LM detection methods on ergonomic applications.

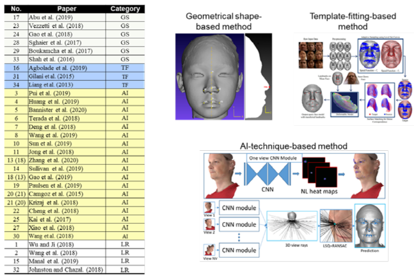
Database

No.	Database	Features	Sample	Source	Accessibility
1	Bosphorus	▪ Images: 4666 3D faces ▪ Subj.: 105 ▪ Variability: expressions, poses, occlusions ▪ Landmark: 22		http://bosphorus.ee.boun.edu.tr	Free (only 2D image available)
2	FRGCv2	▪ Images: 4007 ▪ Subj.: 466 ▪ Variability: expressions ▪ Landmark: 8 ▪ UND: 1680, 537, rotation		https://cvrl.nd.edu/projects/data/#face-recognition-grand-challenge-frgc-v20-data-collection	Free
3	BU_3DFE	▪ Images: 2400 3D facial models ▪ Subj.: 100 ▪ Variability: expressions, angles (about ±45 ◦yaw angle) ▪ Landmark: 83		http://www.cs.binghamton.edu/~lijun/Research/3DFE/3DFE_Analysis.html	Commercial
4	BU_4DFE	▪ Images: 60600 3D face frames with 6 videos ▪ Variability: expressions			
5	FaceBase	▪ Images: 444 3D facial scan ▪ Subj: 369 (age: 1-75) ▪ Variability: genetic syndrome ▪ Landmark: 12		www.facebase.org	Free
6	DTU-3D	▪ Subj: 601 ▪ Landmark: 73		-	Not available
7	Stirling/ESRC	▪ Subj: 101 ▪ Variability: expression ▪ Landmark: 16		http://pics.stir.ac.uk/ESRC/index.htm	Free

Landmark



Method



Evaluation criteria

	Accuracy	Efficiency
Method	Comparing the detected LM locations with the ground truth LM locations	Comparing the computational cost
Measure	▪ Mean error of each landmark of all subjects ▪ Overall mean error ▪ RMSE (root mean square error) ▪ Ratio within a specified error range	▪ Training time ▪ Detection time

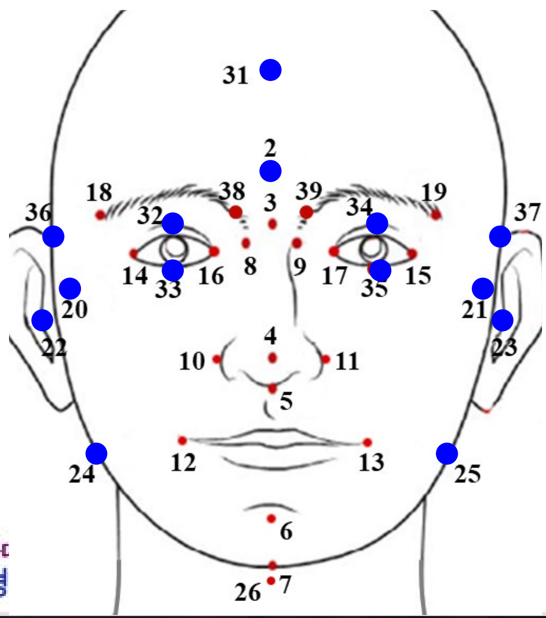
Evaluation performance

No.	Database	Features	Detected LMs	Mean error	Reference
1	Bosphorus	▪ Images: 4666 3D faces ▪ Subj.: 105 ▪ Variability: expressions, poses, occlusions ▪ Landmark: 22	▪ 7 LMs ▪ 8 LMs ▪ 10 LMs ▪ 22 LMs ▪ 83 LMs (manually extracted)	▪ 0.8 - 1.5 mm ▪ 2.7 - 7.2 mm ▪ 2.4 - 5.2 mm ▪ 2.1 - 6.0 mm ▪ 6.98 ± 3.94 mm (all)	[24] [23] [21] [25] [10]
2	FRGCv2	▪ Images: 4007 ▪ Subj.: 466 ▪ Variability: expressions ▪ Landmark: 8 ▪ UND: 1680, 537, rotation	▪ 7 LMs ▪ 7 LMs ▪ 10 LMs (FRGC+UND) ▪ 14 LMs	▪ 2.9 - 3.7 mm ▪ 1.2 - 6.9 mm ▪ 3.1 - 4.8 mm ▪ 2.66 ± 1.89 mm (all)	[22] [24] [21] [13]
3	BU_3DFE	▪ Images: 2400 3D facial models ▪ Subj.: 100 ▪ Variability: expressions, angles (about ±45 ◦yaw angle) ▪ Landmark: 83	▪ 4 LMs ▪ 7 LMs ▪ 11 LMs ▪ 14 LMs ▪ 14 LMs	▪ 3.3 - 4.9 mm ▪ 4.2 – 17.2 mm ▪ 1.8 – 3.0 mm ▪ 2.6 - 4.7 mm ▪ 1.5 – 2.8 mm	[24] [3] [19] [10] [13]

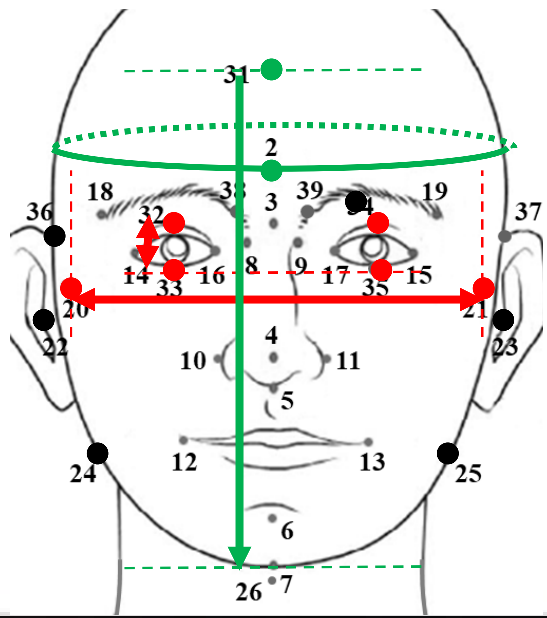
Discussion (2/4)

- A 3D facial landmark detection method for key landmarks of ergonomic applications (e.g., anthropometric measurement and product design) with high performance needs to be developed.
- A hybrid method combining template-, AI-, and geometry-methods is promising to customize LM detection to satisfy the detection requirement in ergonomics.

LMs almost missed detection in current studies

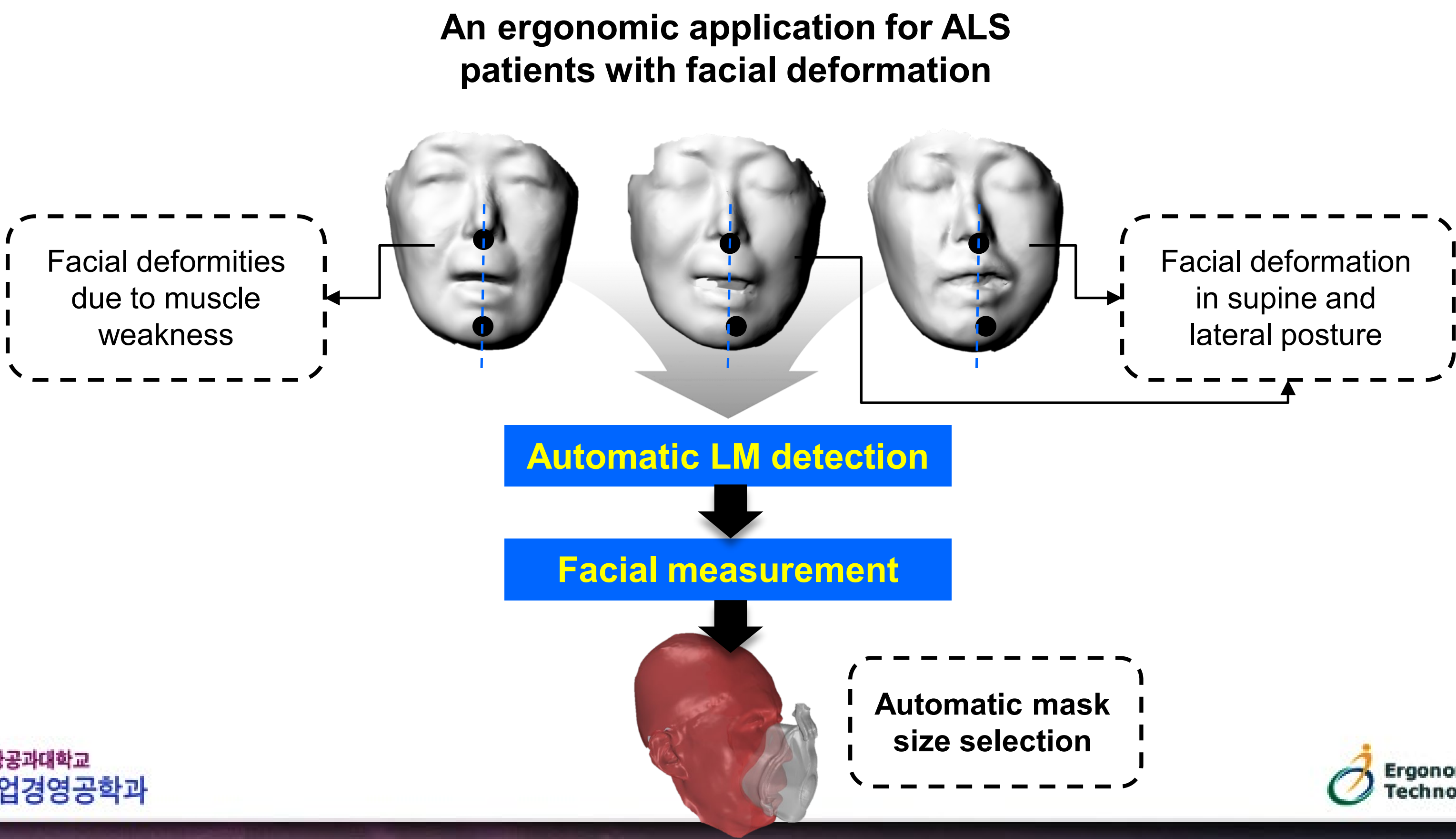


Key landmarks for ergonomic design



Discussion (3/4)

- The performance (accuracy, efficiency, and stability) for particular users (with facial deformities, large-scale poses, various expressions, extreme illuminations, and partial occlusions) needs to be improved for ergonomic applications in real-world scenarios.



Discussion (4/4)

- An evaluation protocol to verify the effectiveness of detected LMs for facial dimension measurement need to be developed.

Evaluation protocol

Detection process

Initialization
- Initial landmark detection based on **CNN method**

→

LM customization on template face
- Localization of **customized** LMs on template face

→

Automatic LM detection on target faces
- Automatic LM detection on target faces based on **template-fitting method**

Hybrid 3D facial LM detection

↓

Verification process

Dataset including facial dimension information
- Facial dimension measurement based on **manually localized LMs**

VS.

Facial dimension measurement
- Dimension measurement based on **automatically extracted LMs**

↓

Evaluation
- Evaluate the effectiveness based on the RMSE between the facial dimensions obtained manually or automatically

경청해 주셔서 감사합니다.

본 연구는 양산부산대학교병원 의생명융합연구소의
인큐베이팅 연구과제의 지원을 받아 수행된 결과입니다.