INDUSTRIAL AND MANAGEMENT ENGINEERING, POSTECH

TU Delft Delft University of Technology

Ergonomic Design Technology Lab

3D Scan to Product Design: Methods, Techniques, and Cases

Wonsup Lee[1,2], Baekhee Lee[2], Sungho Kim[2], Hayoung Jung[2], Eunjin Jeon[2], Teukgyu Choi[3], and Heecheon You[1]

[1] **Faculty of Industrial Design Engineering, Delft University of Technology**

[2] Department of Industrial and Management Engineering, Pohang University of Science and Technology (POSTECH), South Korea

[3] Humanopia Inc., Pohang, Korea

Global Contributor to Eco-Techno-Humanopia

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- 3D Scan to Product Design
  - ✓ Establishment of 3D Scan DB
  - ✓ Anthropometric Analysis
  - ✓ Sizing System
  - ✓ Representative Models
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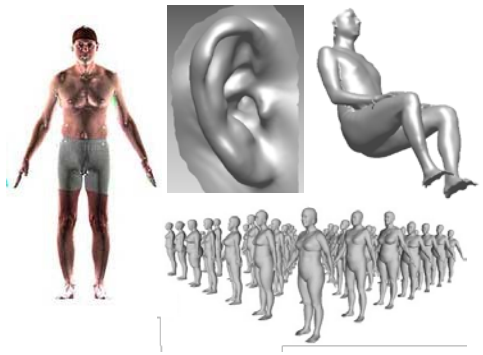
- Discussion

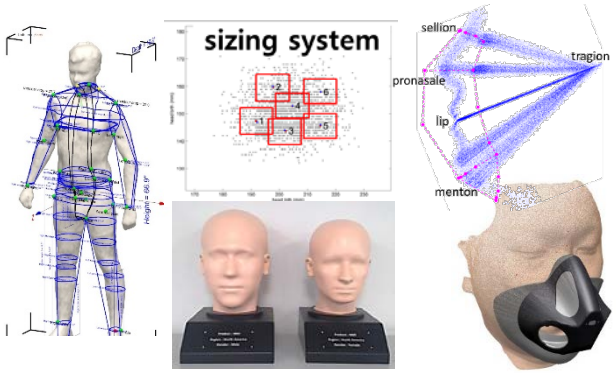
Considerations on '3D Scan to Product Design'

3D scanning



- target user?
  - no. of sample size
  - cost
- which body part?
- posture?
- how to scan?
- editing time

"Analysis & Design"



- measurement?
  - dimensions & landmarks
  - length/curvature/shape/volume
  - mean, SD, range, percentile
- sizing system?
  - type of sizing system
  - no. of sizes
  - accommodation percentage
- representative model?
  - representativeness
  - no. of models
- how to design?
  - virtual prototype
  - parametric design
  - fit simulation

Product

- which product?
- target user?
  - age, gender, ethnicity
- no. of sizes?
- fit?
  - tight fit
  - loose fit
  - comfortable fit
- specifications?
- type of production?
  - mass product
  - customized product
  - mass customization

S1. Establishment of 3D Scan Images

Heads and faces

Korean Air Force pilot (*N* = 336)

oxygen mask

N95 mask

CAESAR North American (*N* = 2,299)

head-related products

Dutch children (*N* = 307)

medical mask

Ear

Korean and Caucasian (*N* = 296)

earphones

Body (torso)

Size Korea elderly woman (*N* = 271)

hip protector

Korean Air Force Pilots

N = 336

- **Rexcan 560 (2006; Solutionix, South Korea), white light projection scanner**
  - ✓ **High resolution**
  - ✓ **Required a dark room**
  - ✓ **Time consumed for processing**
- **Edited, measured, then compared to US Air Force facial measurements**
- **For pilot oxygen mask design**

3D scanned images
(>15 min/person)

image alignment

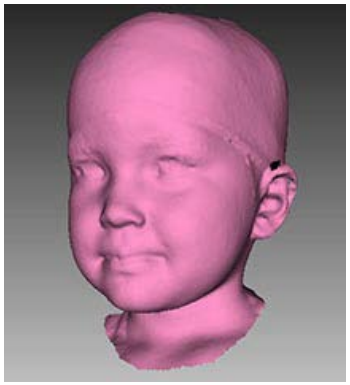
merging
(>60 min/person)

data editing

Dutch Children

N = 307

- Applied 3dMD face scanner
  - ✓ Very fast (<1s)
  - ✓ Colored
- Merged and edited by Artec Studio
- Identified landmarks by 3dMD software
- Measured and analyzed by MATLAB
- Compared to existing children facial measurements by statistic tools
- For medical mask design for Dutch children



http://www.tudelft.nl/en/current/latest-news/article/detail/tu-delft-ontwerpt-beademingsmaskers-voor-kinderen-met-spierziekten/

Ear Scanning

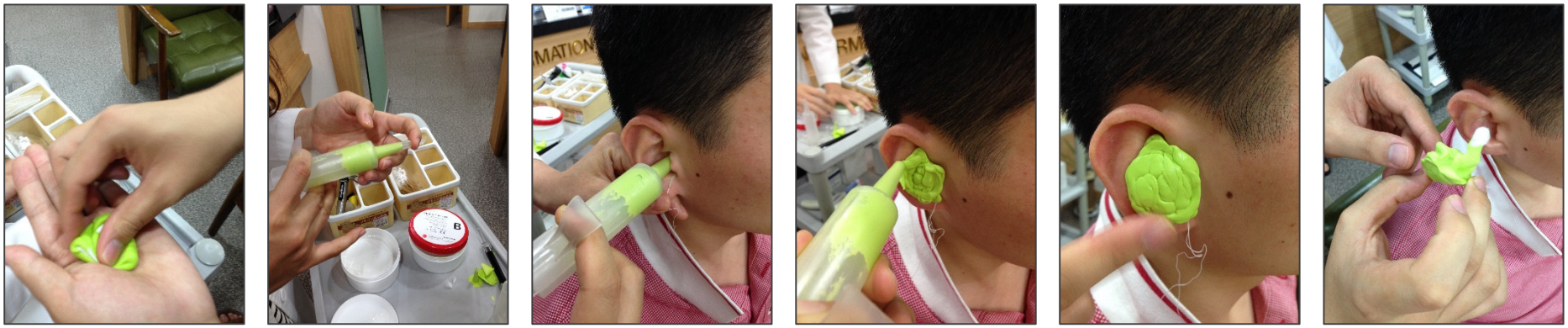
N = 296

- **Artec Eva scanner**

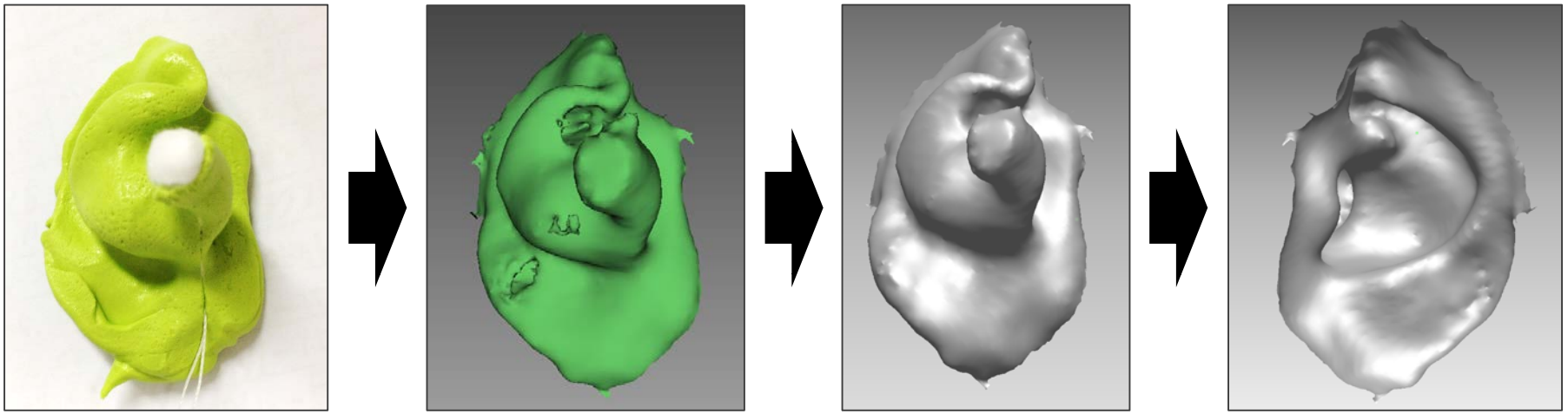
Ear Casting & Scanning

N = 296

- **Casting concha & ear canal (<5 min)**



- **3D scanning of cast (20 ~ 40 min)**

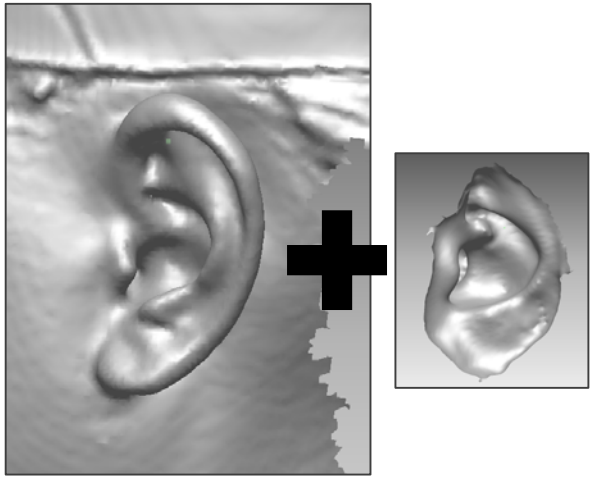


3D scanning *editing* *inverting*

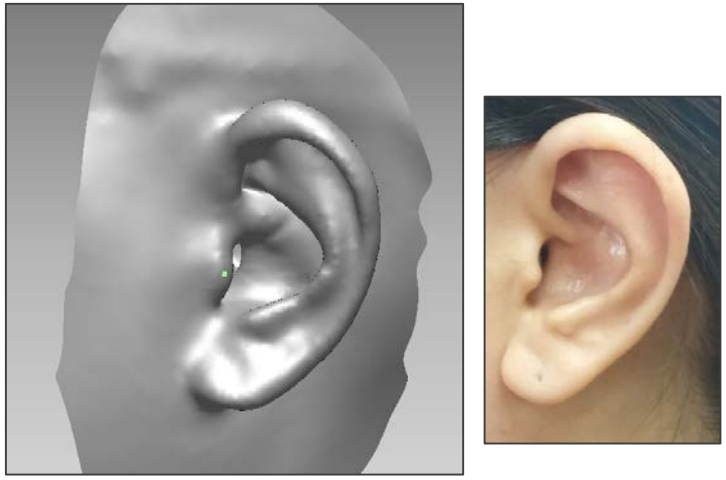
Detailed 3D Ear

N = 296

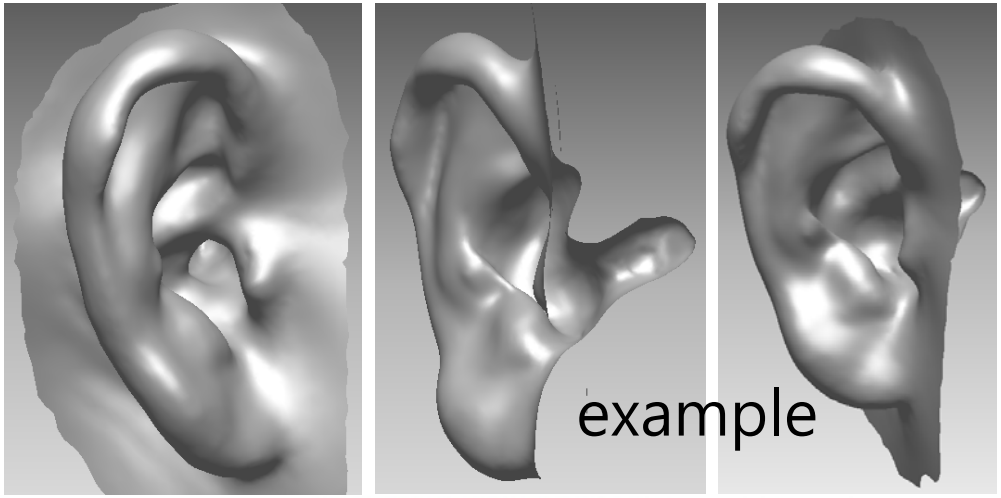
Overall ear + concha/ear canal part



Merged ear



200 Koreans & 96 Caucasians (aged 20~50s, 1:1 gender ratio)

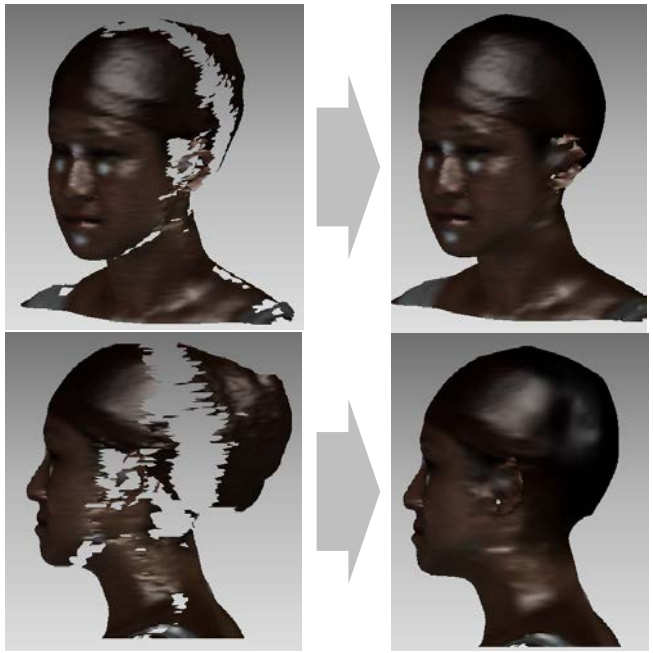


Manual Editing of Existing 3D Scan DB

- **Hole-filling**
- **Smoothing/Defeaturing**
- **Rotation/Alignment**

- **Elimination of unnatural features**
  - **hair style,**
  - **beard,**
  - **clothes, etc.**

CAESAR heads (*N* = 2,299) for head product designs

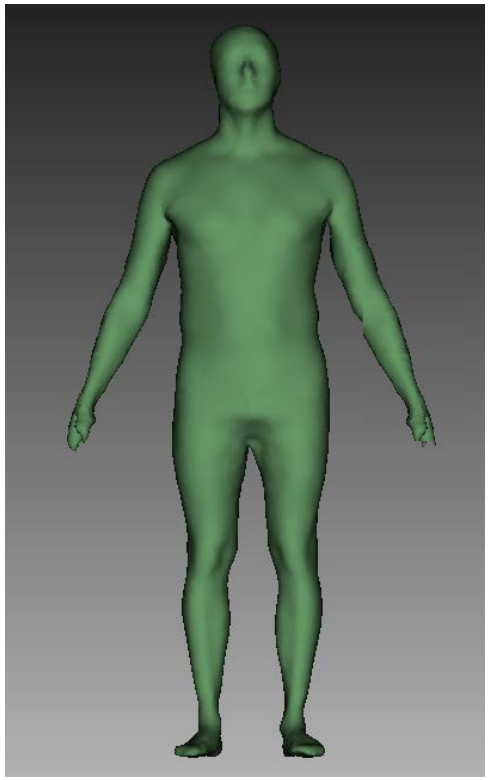


(processing time: 260h)

Size Korea elderly woman (*N* = 271) for hip protector design

Automatic Editing by Template Fitting (on-going)

Template 3D model
(automatically edited)



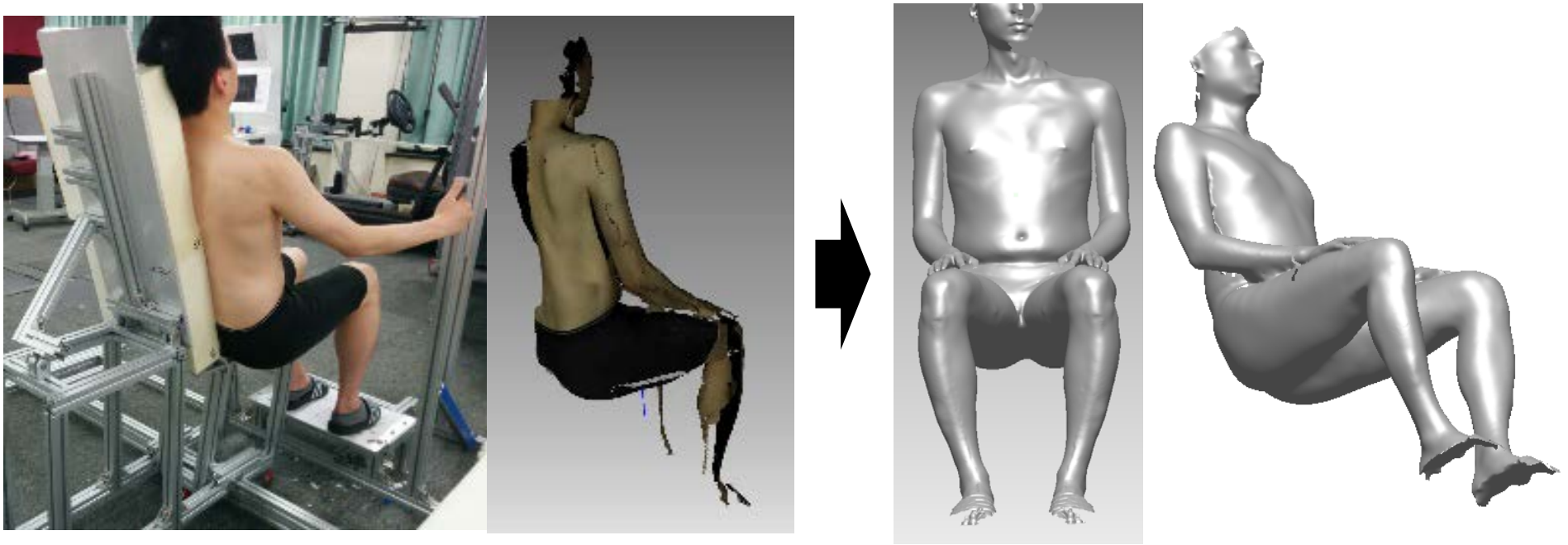
Target 3D image
(required to be edited)

- Features of template model
  - Automatic landmark identification
  - Automatic measurement & feature extraction
  - Calculation of area/volume of body parts
  - Posture change

- Applications
  - Design considered skin deformation
  - Pressure estimation
  - Parametric design

Specialized Scans: Seated Posture

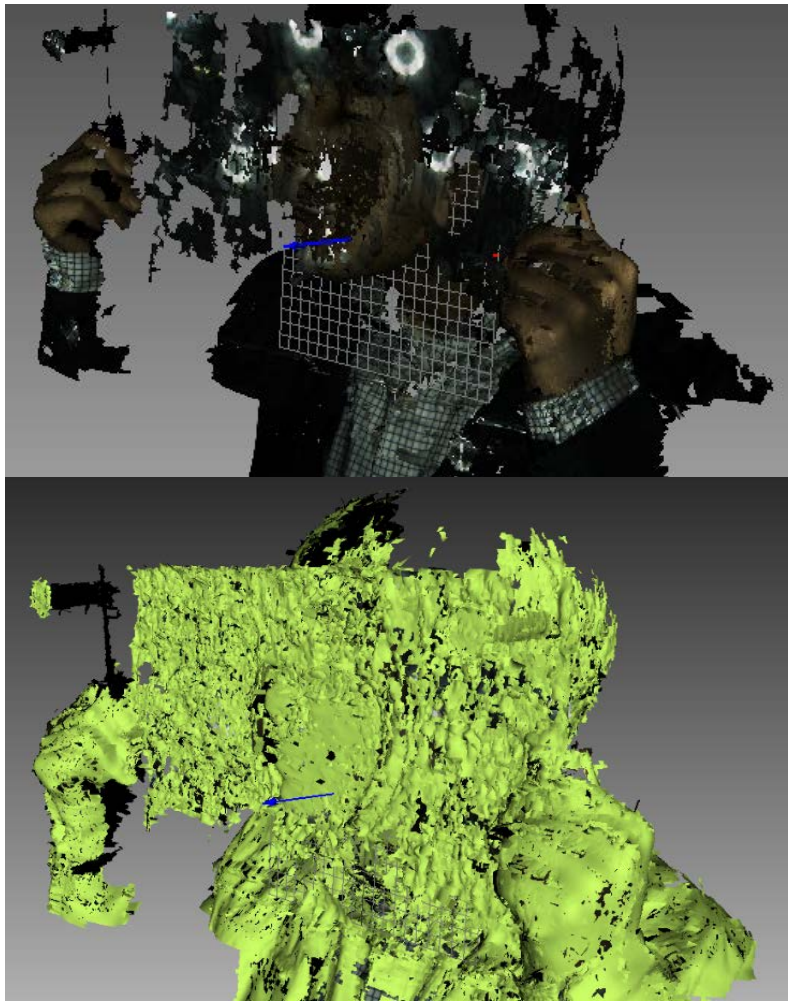
- **Developed specialized equipment for scanning**
- **Scanned left and right side separately, then merged (Artec)**



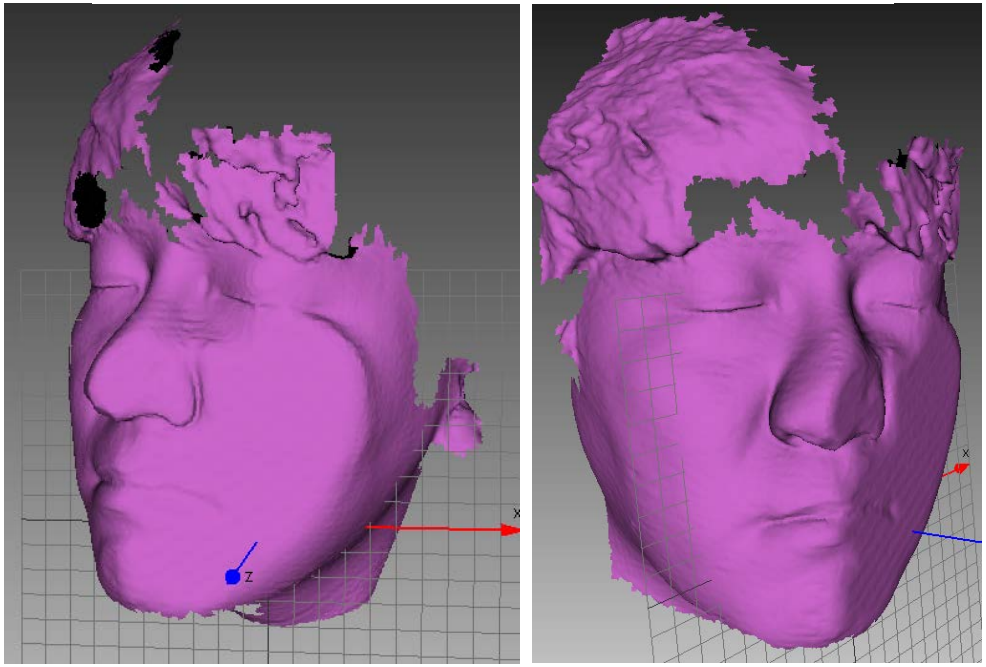
Specialized Scans: Deformed Skin

- 3D scanning for skin deformation study (Artec)

scanning through glass pushing face

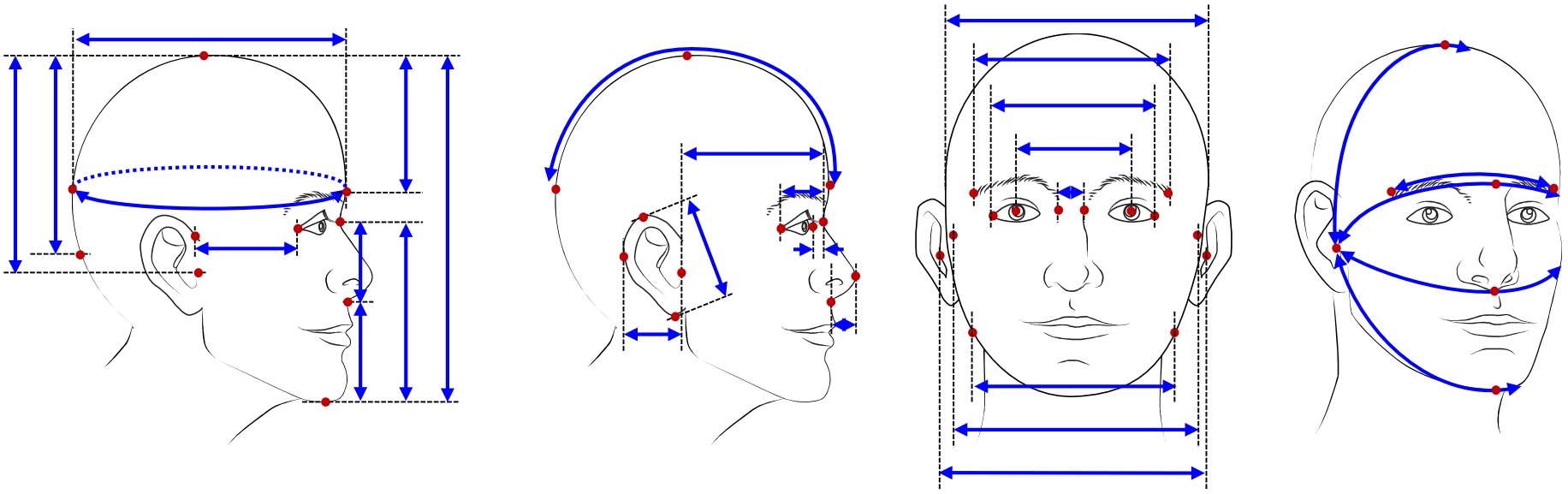


noise filtering & editing



S2. Anthropometric Dimensions: Head and Face

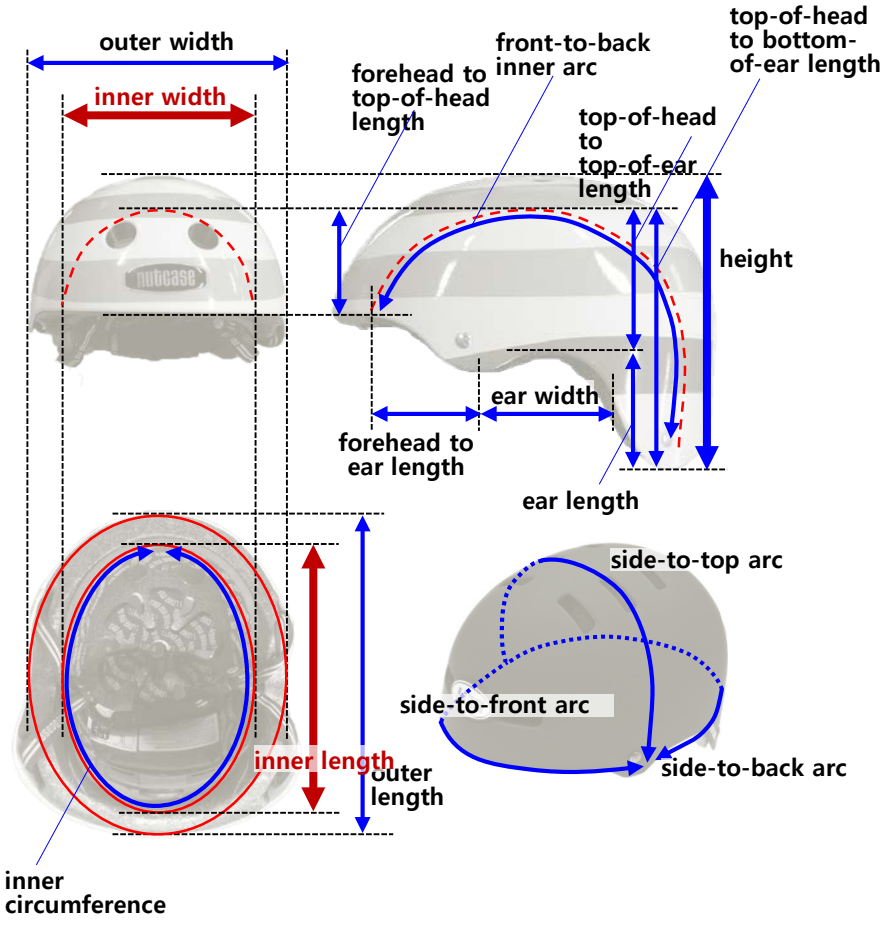
- Identified 122 head dimensions by referring to 18 previous studies
  - ✓ Length dimensions: 53
  - ✓ Depth dimensions: 29
  - ✓ Width dimensions: 18
  - ✓ Circumference/arc dimensions: 22
- Selected dimensions related to product design
- Identified new dimensions based on existing facial landmarks



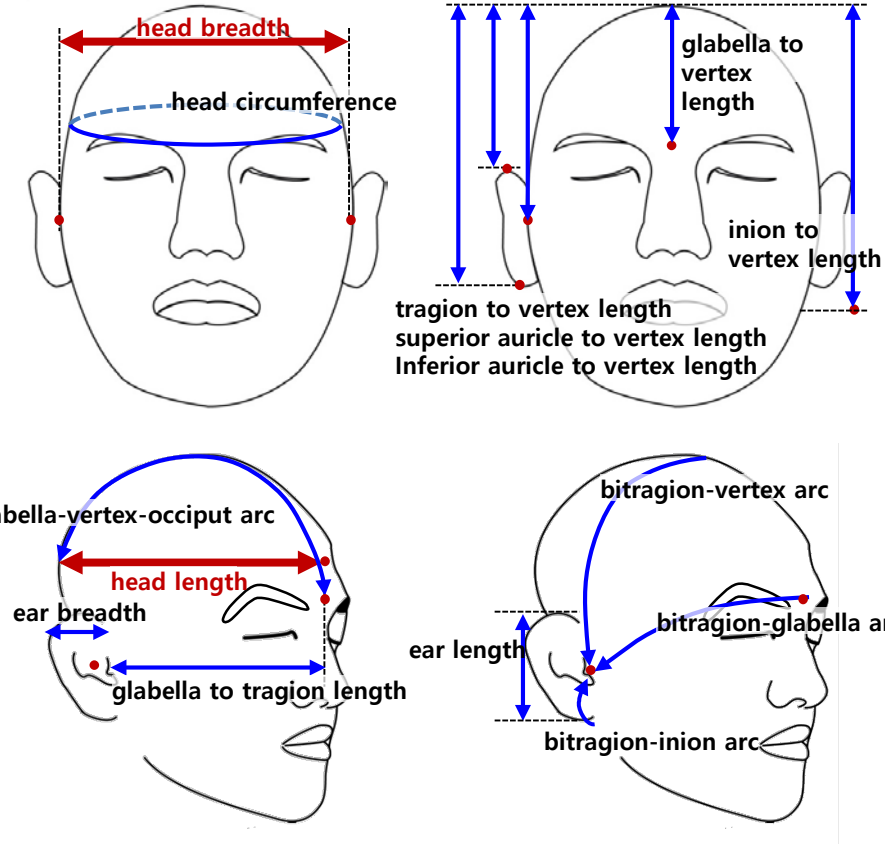
Selection of Anthropometric Dimensions: Helmet

- By analysis of **design dimensions** and **related head dimensions**

Design dimensions (16)



Head dimensions (18)

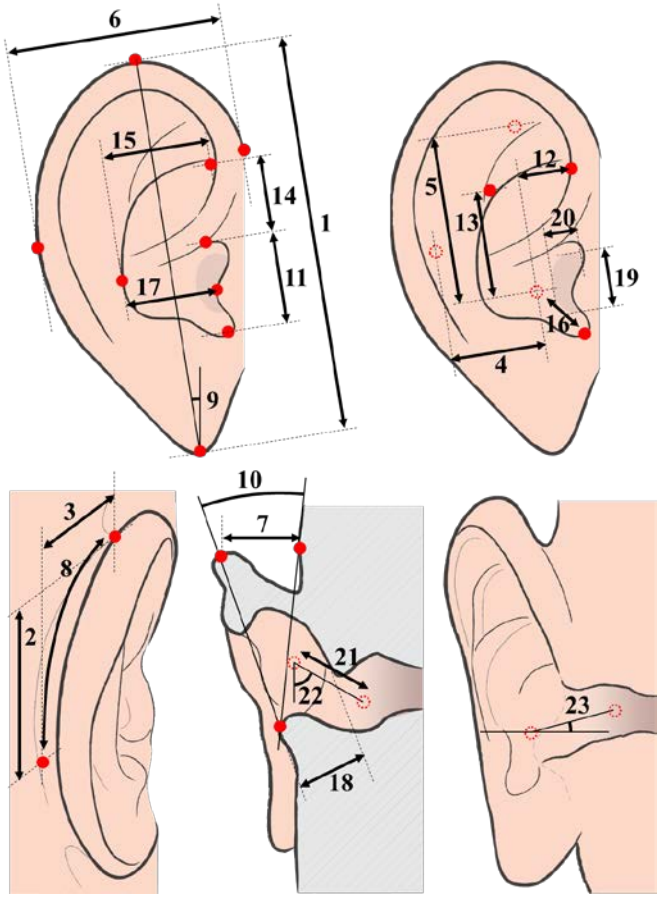


red: key dimensions

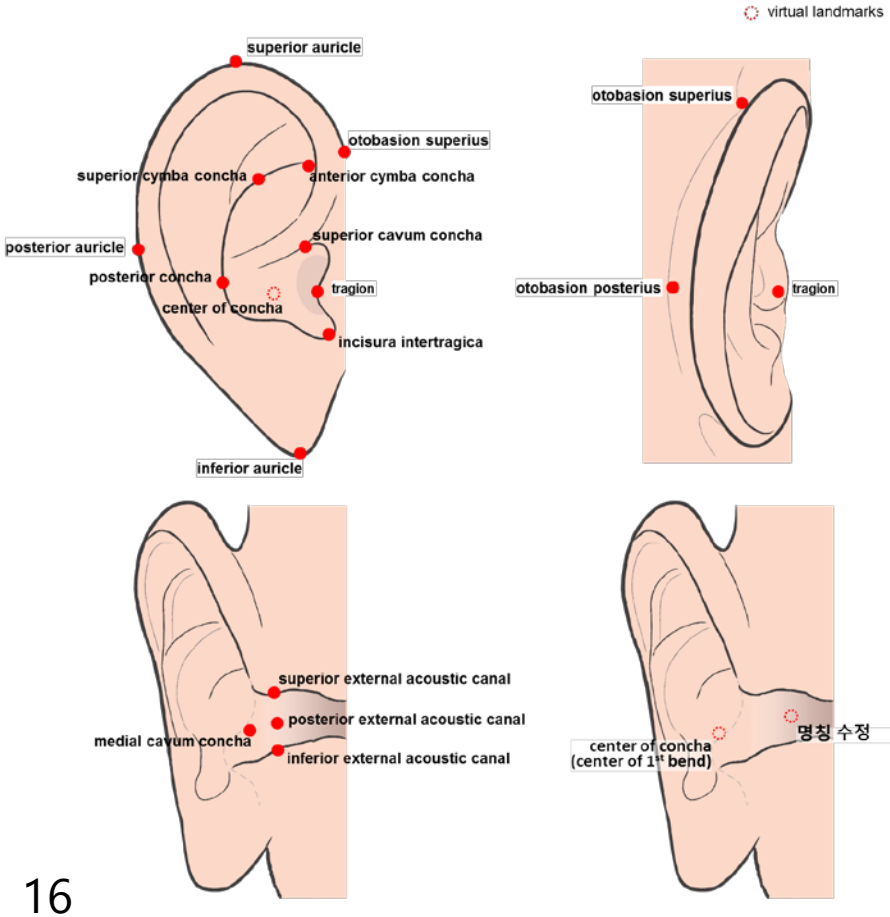
Anthropometric Dimensions: Ear

- Identified 22 ear dimensions by referring to 15 previous studies
- Proposed additional 14 ear dimensions for earphone design

Ear dimensions for earphone design

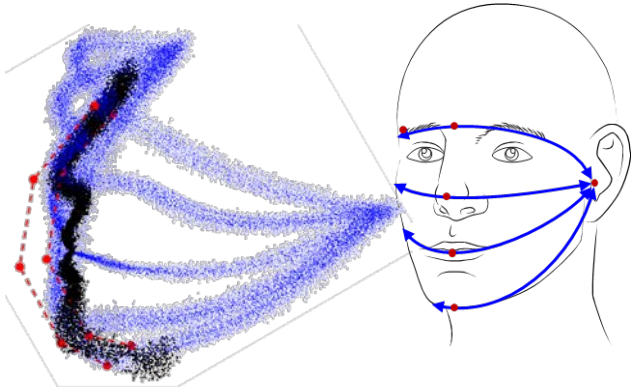


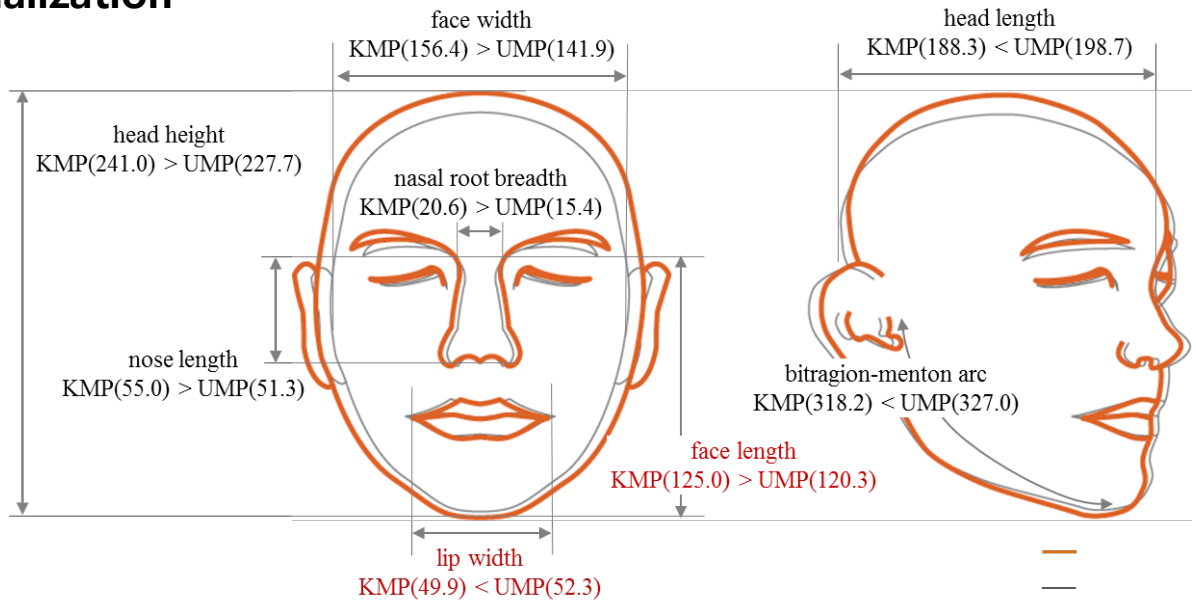
Related ear landmarks



Measurement & Comparison

- **Automatic measurement & analysis by an in-house software developed using MATLAB**
  - **Automatic alignment**
  - **Landmark classification**
  - **Measurement (dimensions, curvature, area, volume)**
  - **Shape analysis (e.g., curvature extraction)**
  - **Comparison of measurement**
  - **Visualization**





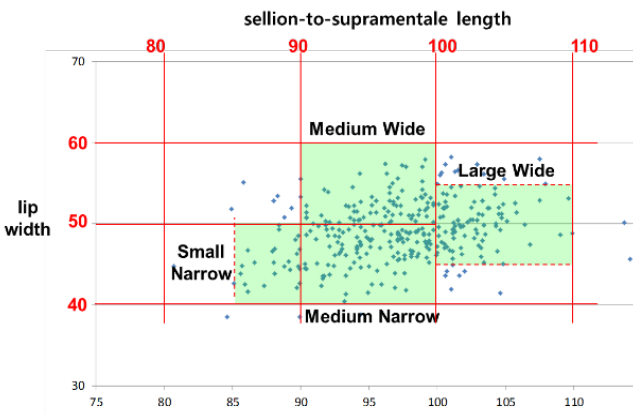
Korean Air Force pilots vs. US Air Force personnel

S3. Sizing System

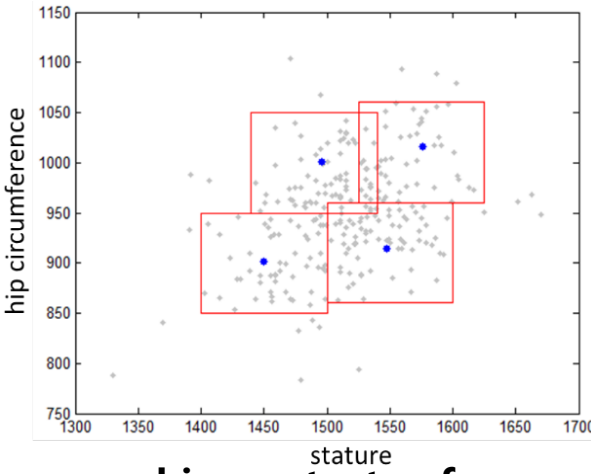
- **Statistic-based** sizing system generation

Stature / Chest circumference	Small < 168	Medium < 173	Large < 178	Special < 183	Special large < 190
85 (82.5~87.4)	0.9 %	3.2 %	2.1 %		
90 (87.5~92.4)	1.6 %	7.2 %	8.1 %	2.9 %	
95 (92.5~97.4)	1.9 %	10.1 %	12.2 %	5.5 %	1.1 %
100 (97.5~102.4)	0.9 %	5.3 %	10.8 %	6.8 %	2.1 %
105 (102.5~107.4)		2.2 %	4.2 %	3.5 %	1.2 %
110 (107.5~112.4)			1.5 %	1.2 %	

Korean Air Force pilots flight suit (23 sizes)



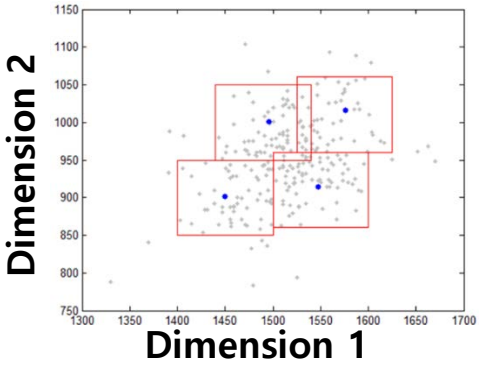
Air Force pilot oxygen mask (4 sizes)

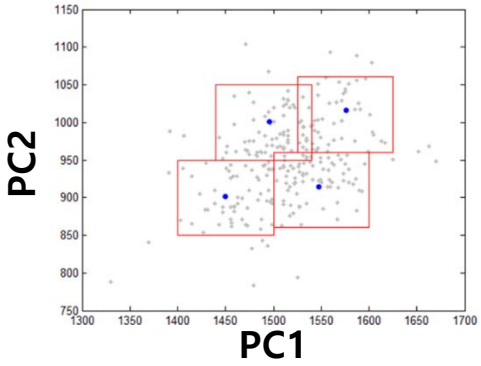


hip protector for Korean elders (4 sizes)

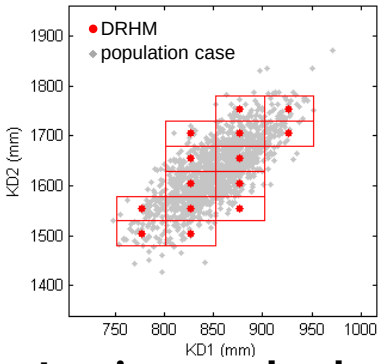
Considerations for Sizing System Generation

- **Key dimensions selection** method
  - Selection by designer
  - Selection through statistical analysis (e.g., factor analysis, PCA, regression)

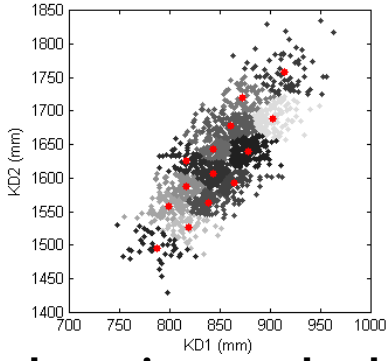




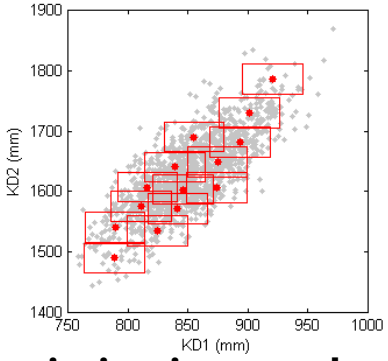
- **Grid formation** method



Lattice method (traditional method for apparel design)



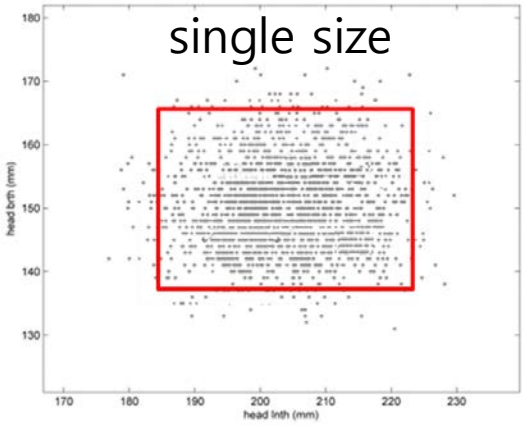
clustering method (Laing et al., 1999)

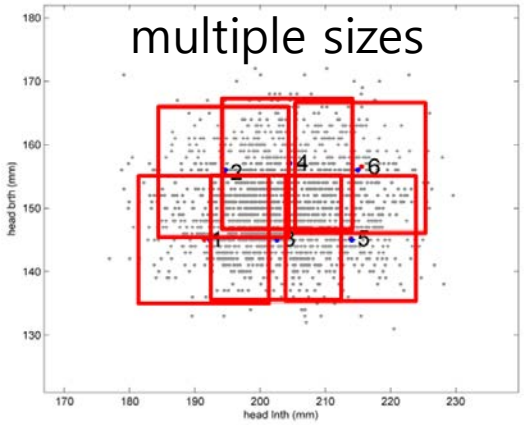


optimization method (McCulloch et al., 1998)

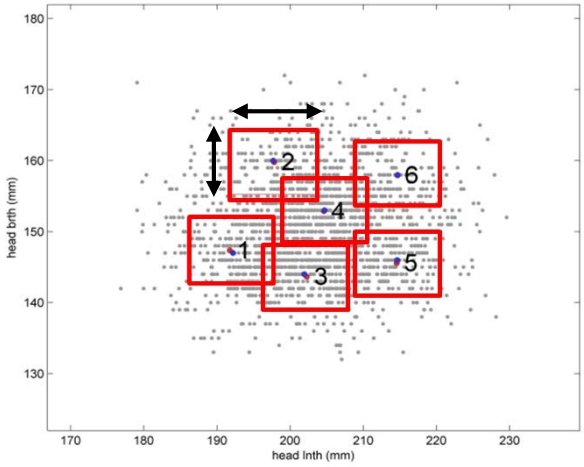
Considerations for Sizing System Generation (cont'd)

- **Number of size categories**

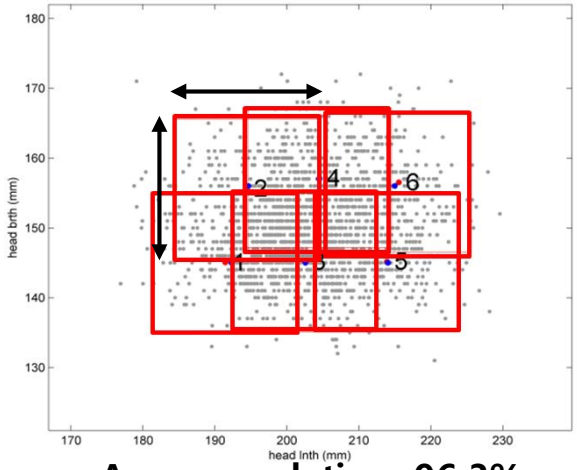




- **Accommodation** percentage
- **Tolerance** of each category (static product vs. flexible/adjustable product)



Accommodation: 72%



Accommodation: 96.3%

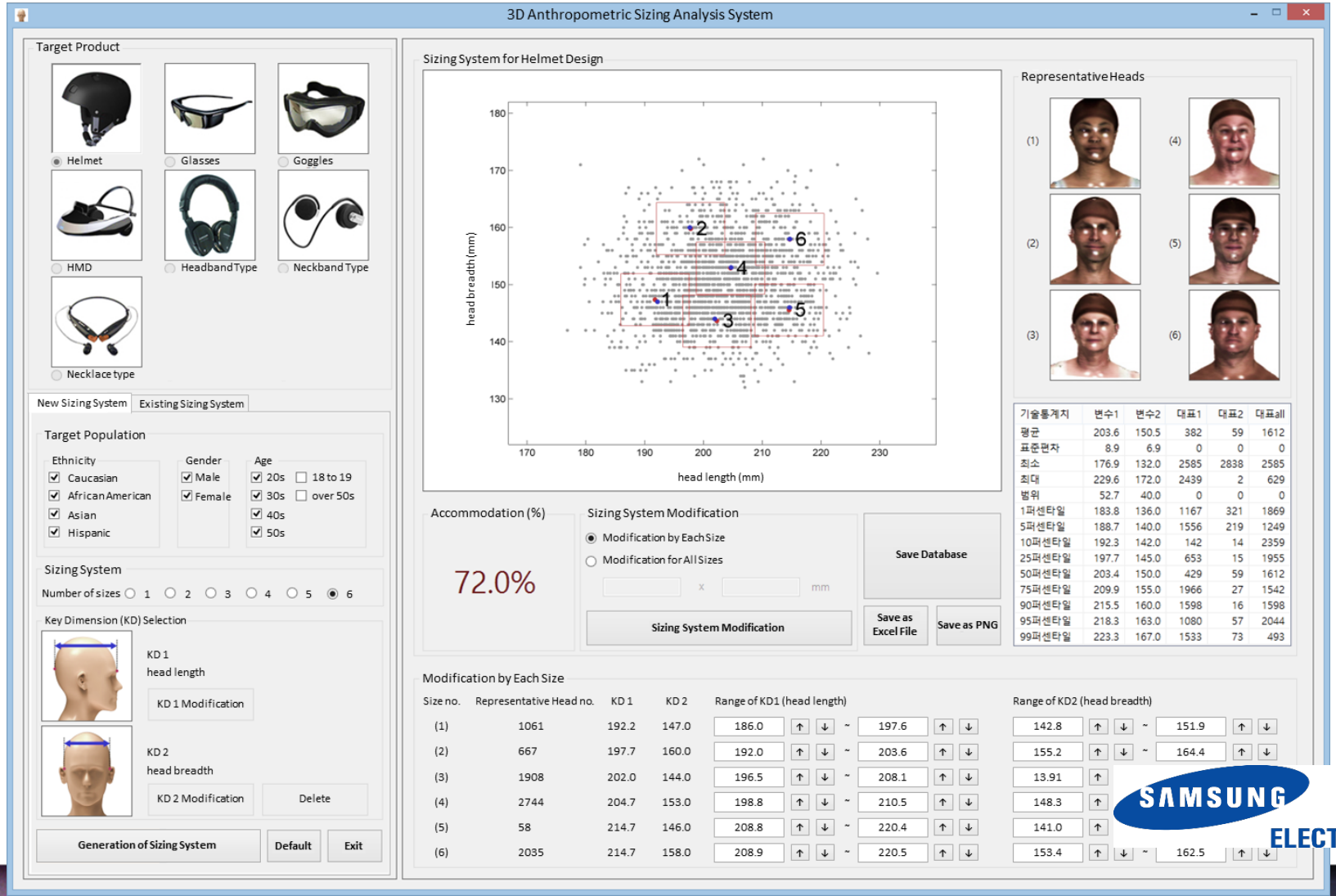
Computerized Program for Sizing System Analysis

- To make **statistical analyses easy and simple**

(planned to be commercialized)

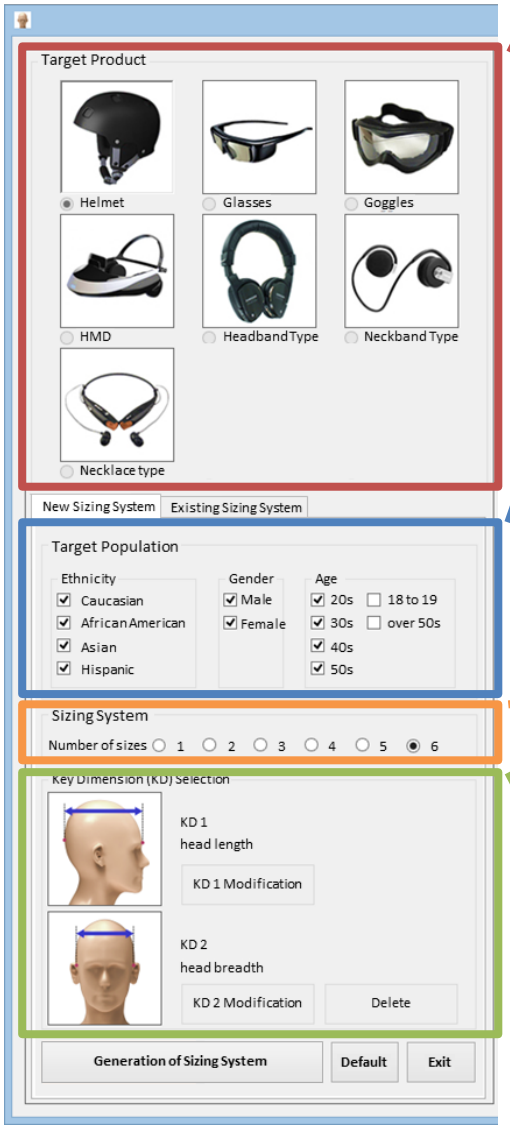
Development of 3D Anthropometric Sizing Analysis System

- Simplified version of sizing analysis program for designers in SAMSUNG
- Based on CAESAR head measurements



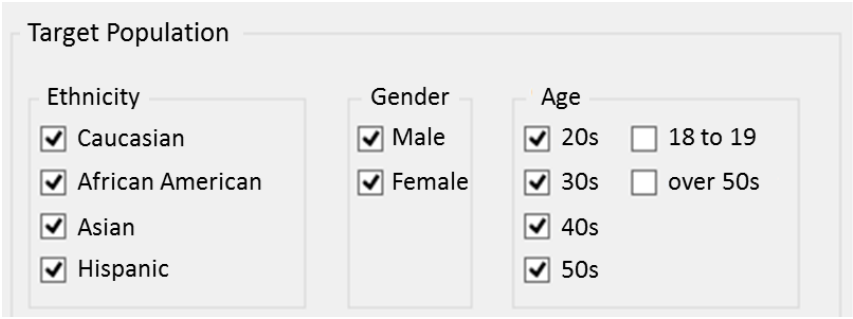
SAMSUNG ELECTRONICS

User Interface: Input

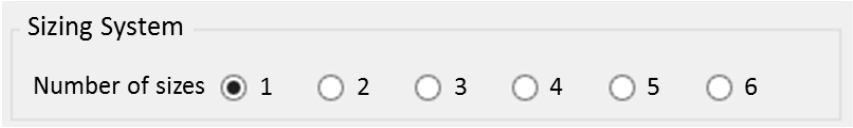


S1. Selection of target product

S2. Selection of target population



S3. Selection of number of size categories in sizing system



S4. Selection of key anthropometric dimensions

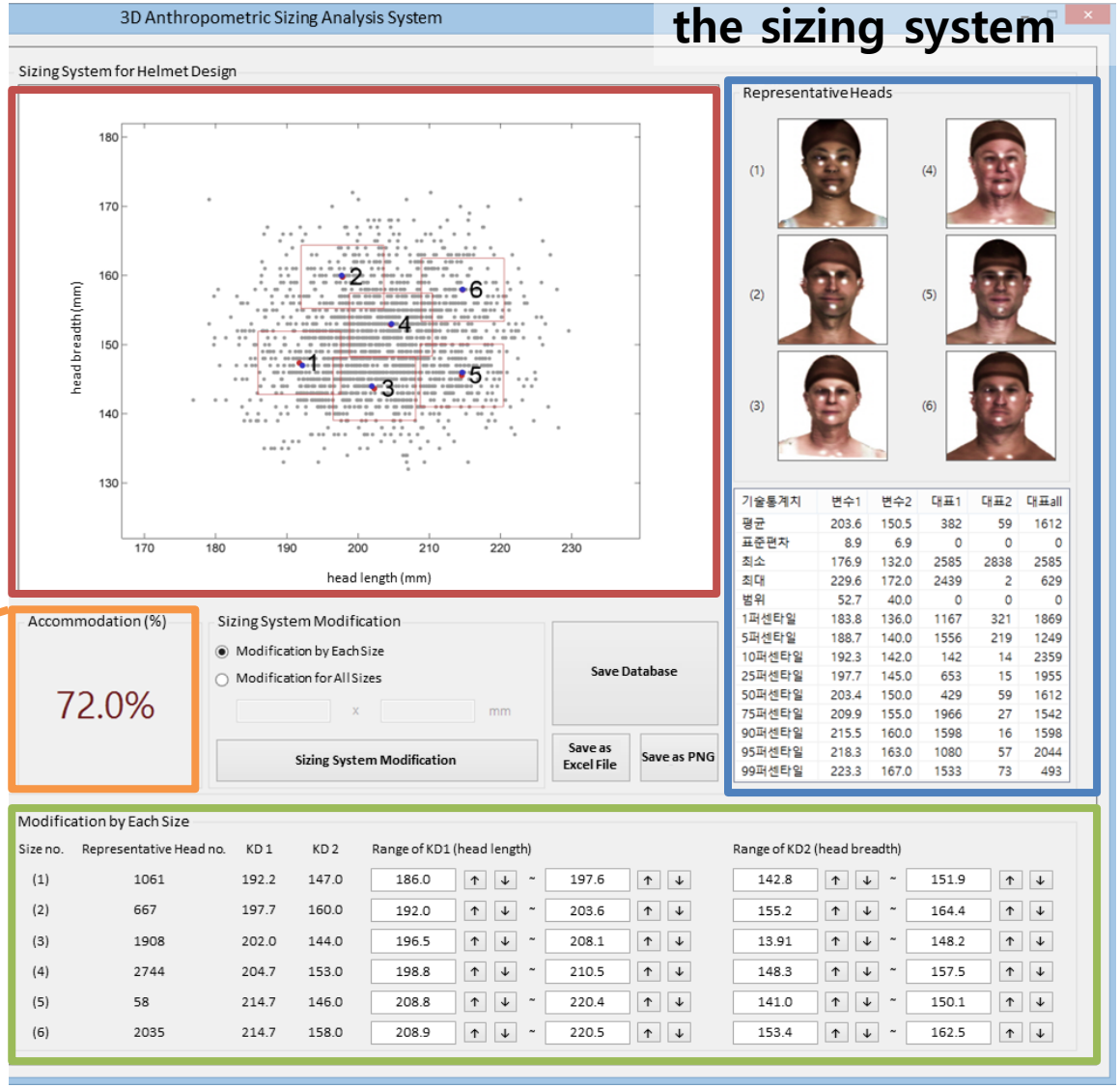
User Interface: Output

Sizing system suggested by the software

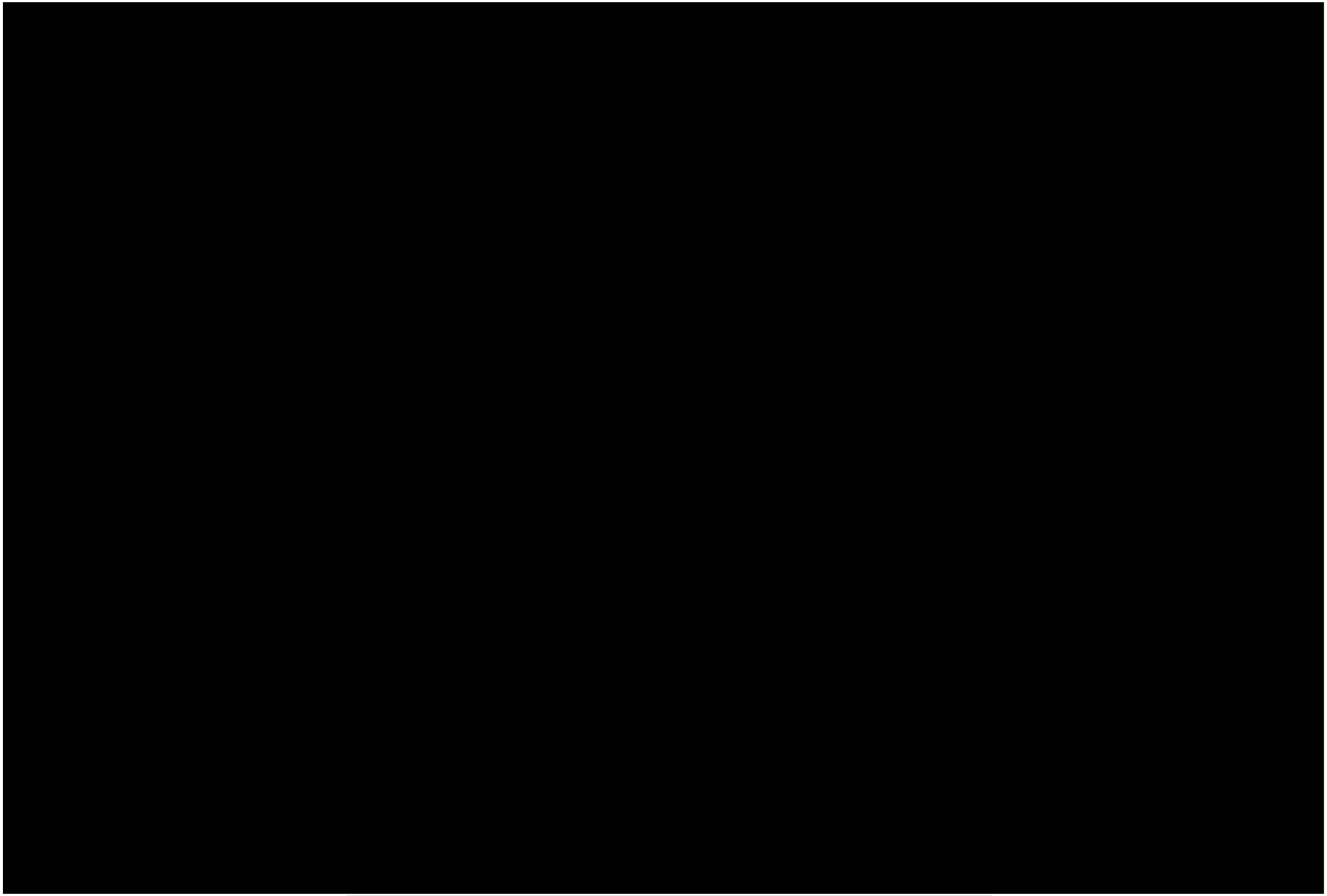
Accommodation percentage of the generated sizing system

User interface for adjustment of the sizing system

Representative heads related to the sizing system



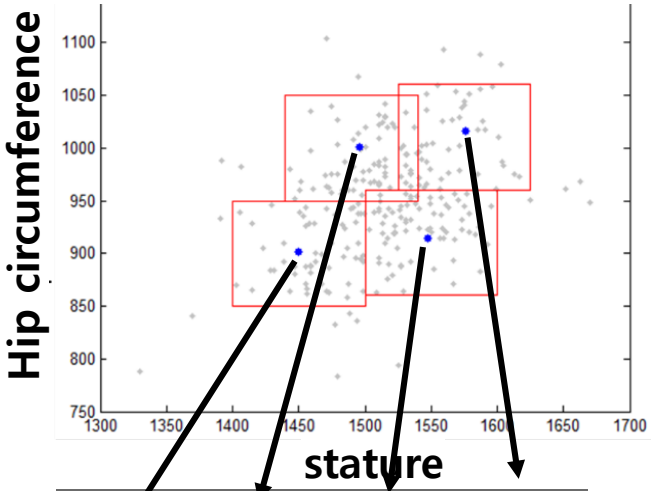
Demonstration of 3D-ASAS

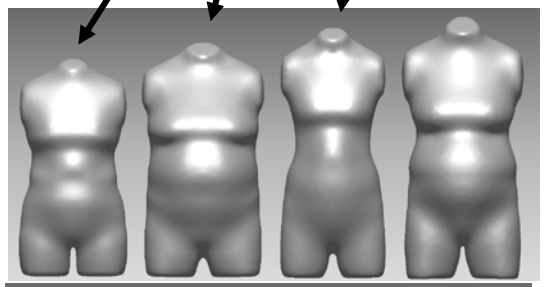


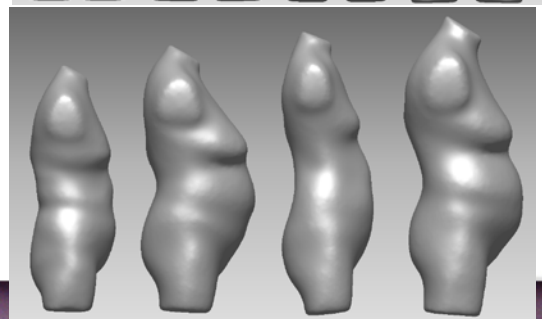
S4. Representative Human Models (RHMs)

- Usually RHMs are **centroid of sizing system**

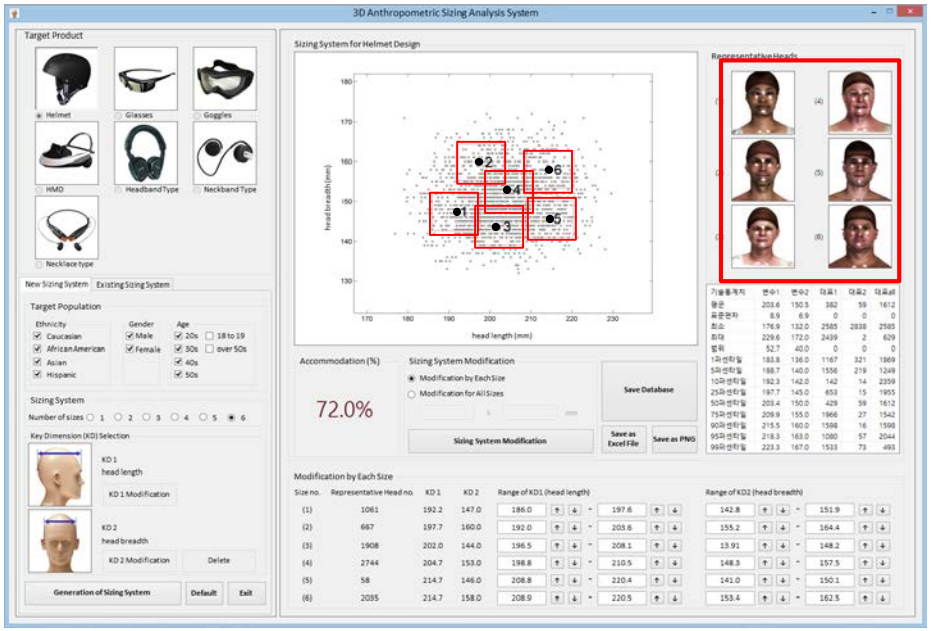
hip protector for Korean elders (4 sizes)





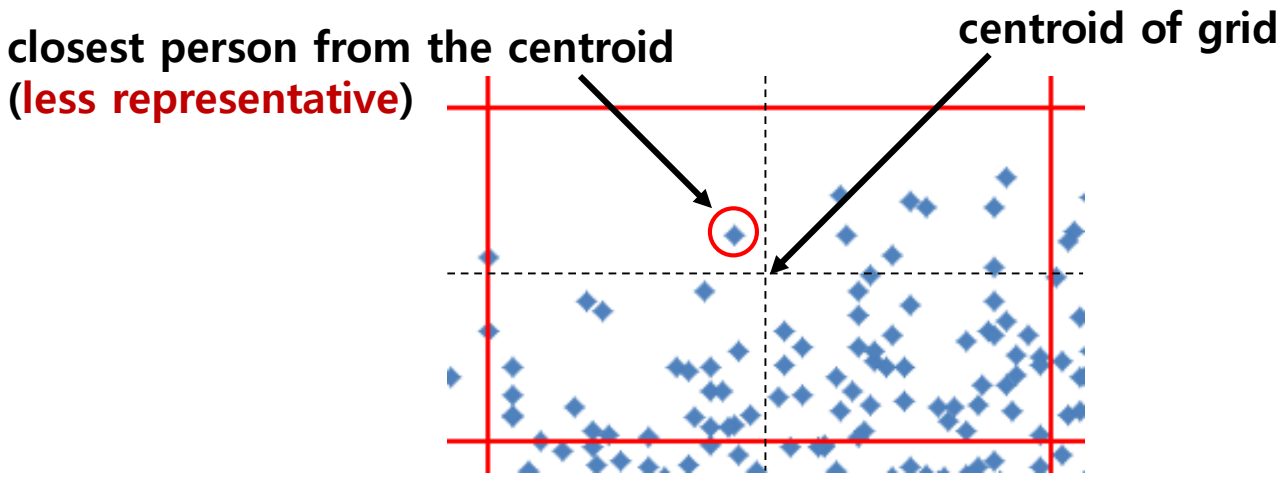


3D-ASAS

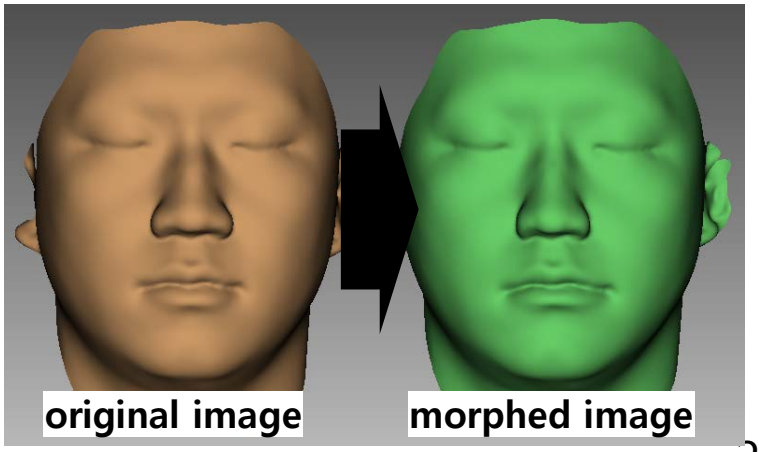


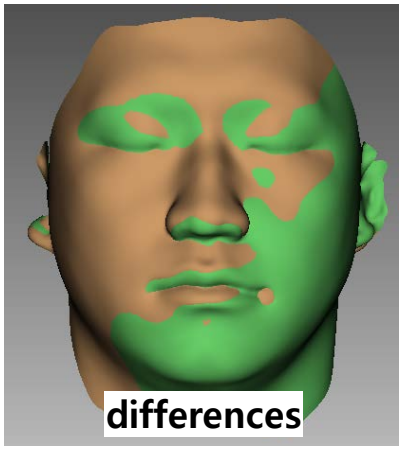
Improvement of Representativeness

- Representative model can be different from centroid



- Minor adjustment for dimensions matching by morphing technique



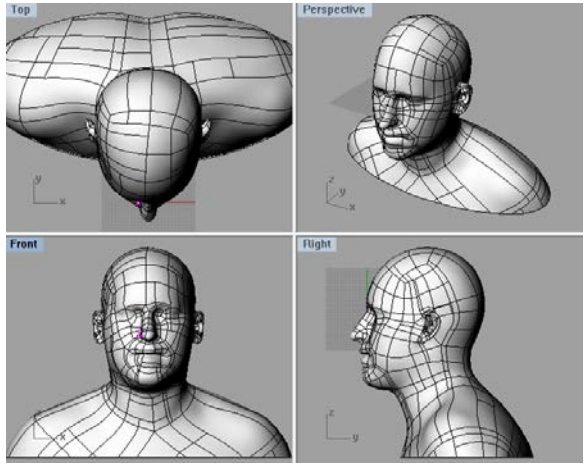


Headforms for Head-Related Product Designs

- **Digital** and **3D-printed** headforms
- 15 general representative heads (5 ethnic group × 3 gender group)
- Developed **based on RHMs** extracted through **3D-ASAS system**

Original CAESAR scan (format: point cloud mesh)

Edited model (format: NURBS)

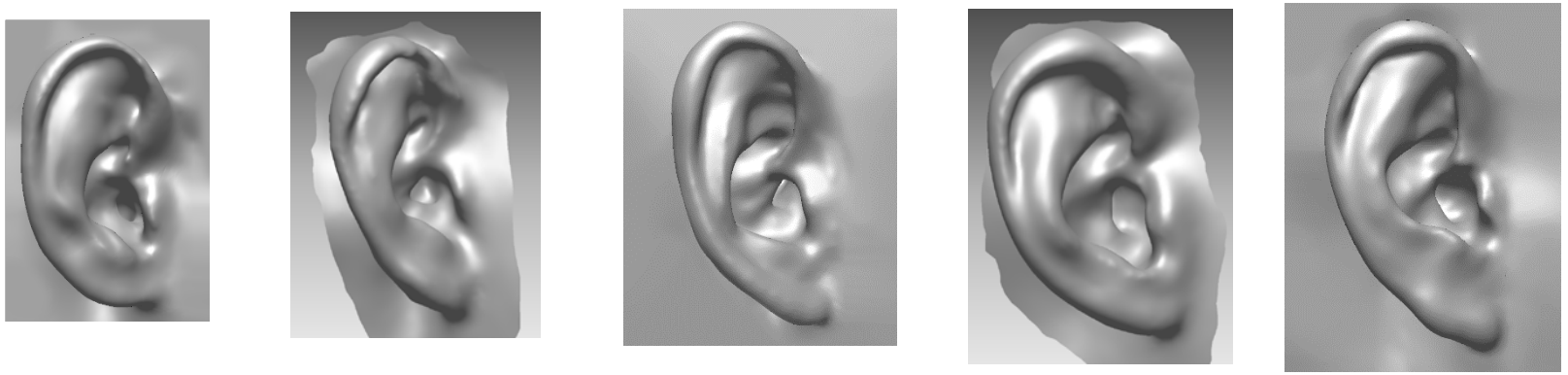


3D printed model

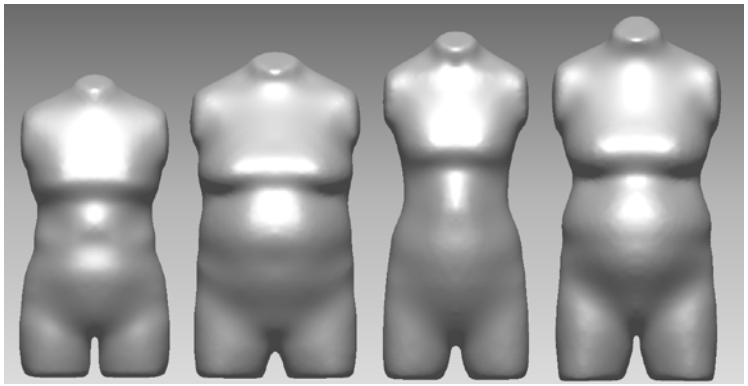
Representative 3D Ear and Torso Models

- **Ear models of Korean and Caucasian for earphone designs**

Smallest (2.5%ile)	Small (25%ile)	Medium (50%ile)	Large (75%ile)	Largest (97.5%ile)

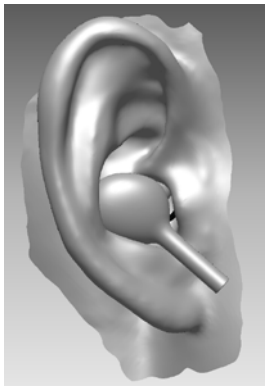


- **Physical mannequins of Korean elderly woman for draping of hip protector**



S5. Product Design Methods

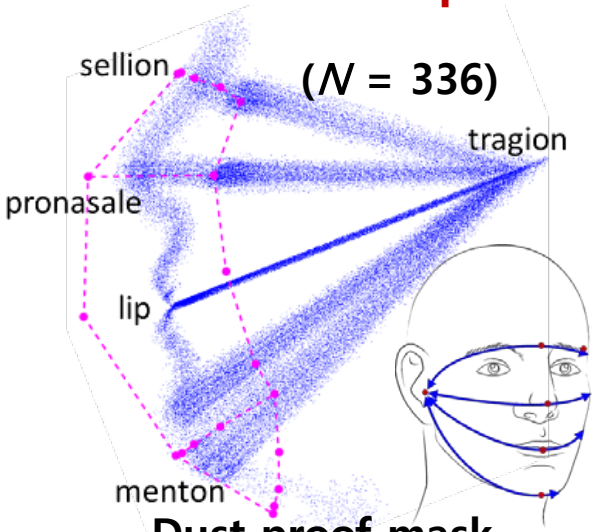
Design based on RHMs/individual scans



Hip protector **Earphone**

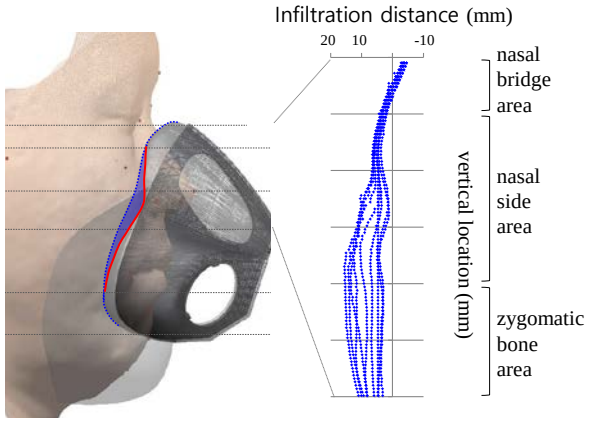
- loose fit product
- adjustable/flexible product
- product with many sizes
- for less varied/simply shaped body part
- e.g., clothes, shoes, helmet, earphone, smart watch
- traditional approach

Design based on massive 3D shapes



Dust-proof mask

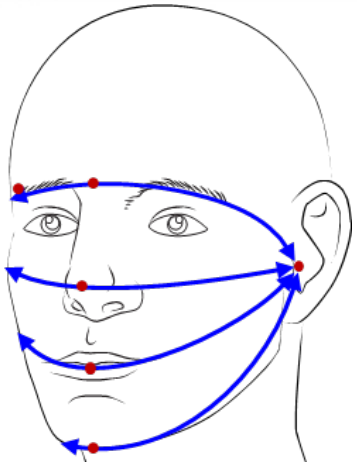
Design based on virtual fit simulation



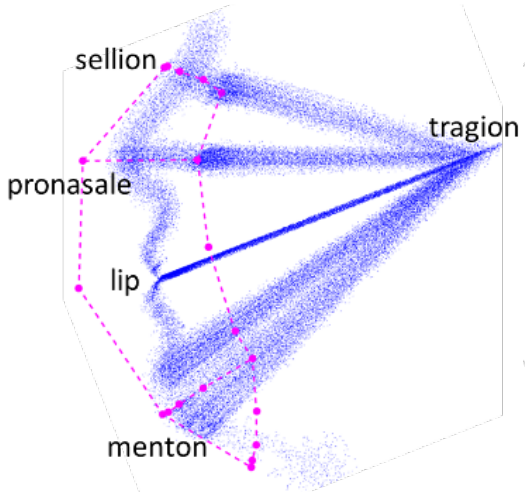
Pilot oxygen mask

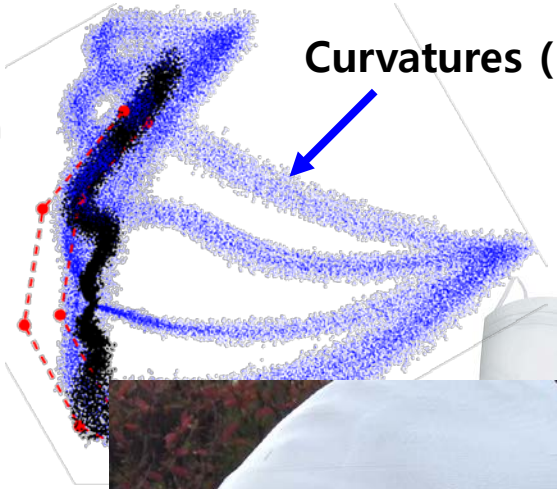
- if fit is important
- product with precise shape
- less adjustable/flexible product
- product with a few sizes
- for complexly shaped body part
- e.g., mask, car seat

Design Based on 3D Shapes: Dust-Proof Mask



Facial curvatures

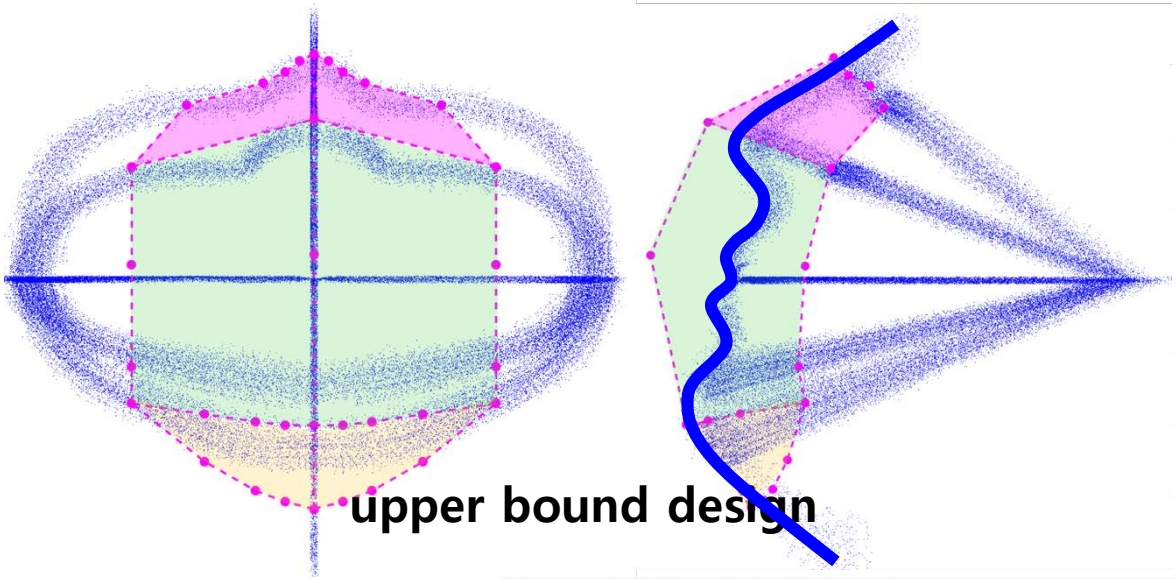




Curvatures (N = 336)

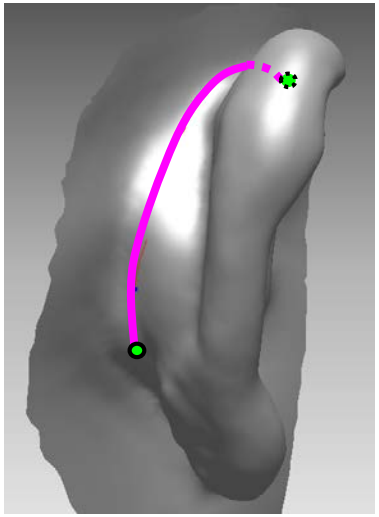
front view

side view

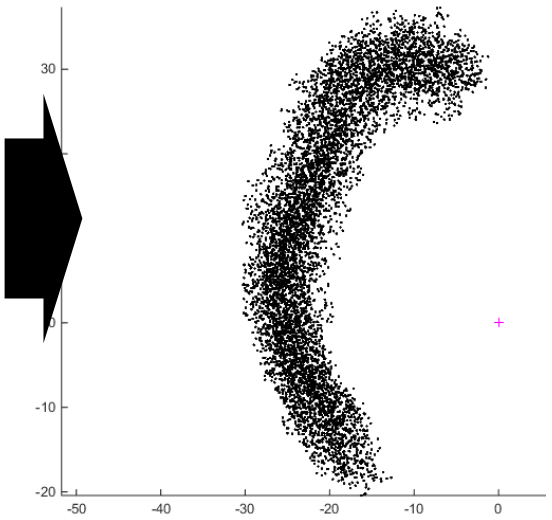


upper bound design

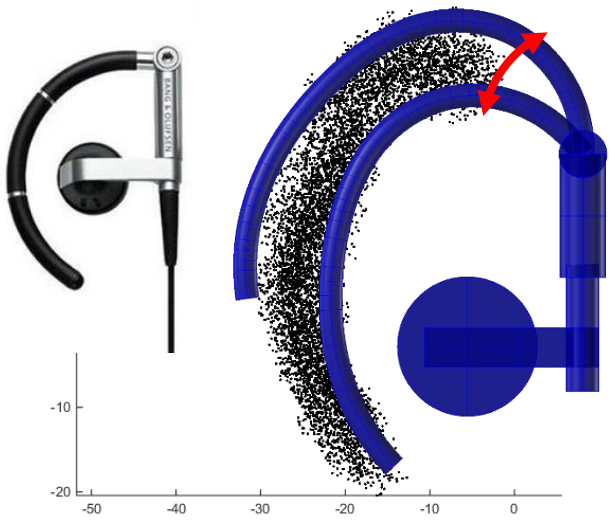
Design Based on 3D Shapes: Earphone Components



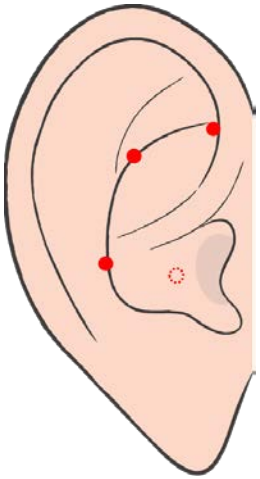
Ear root curvature



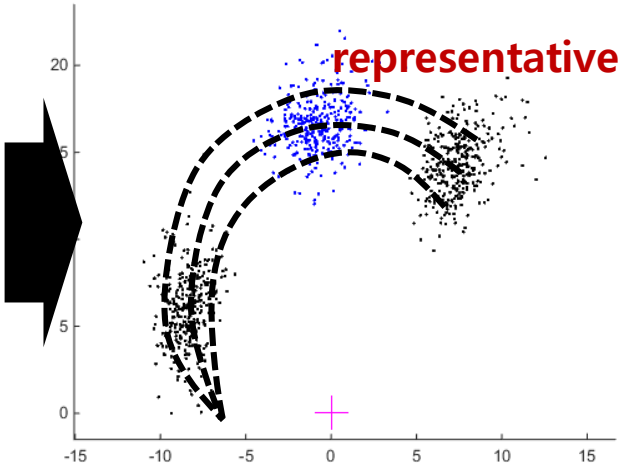
Curvatures (N = 296)



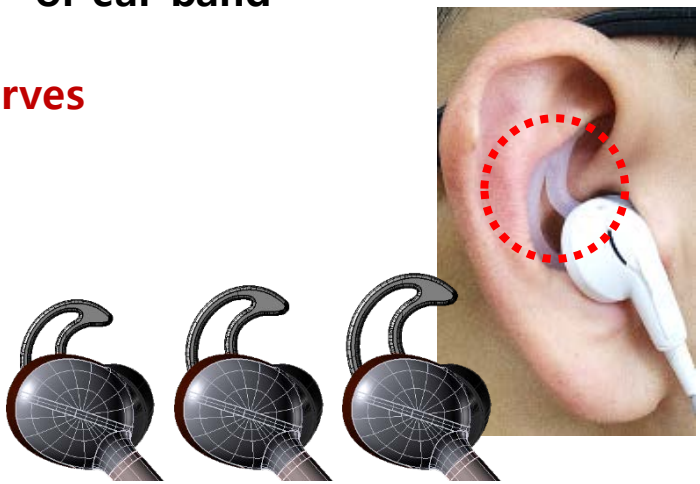
design of adjustment range of ear-band



Ear landmarks



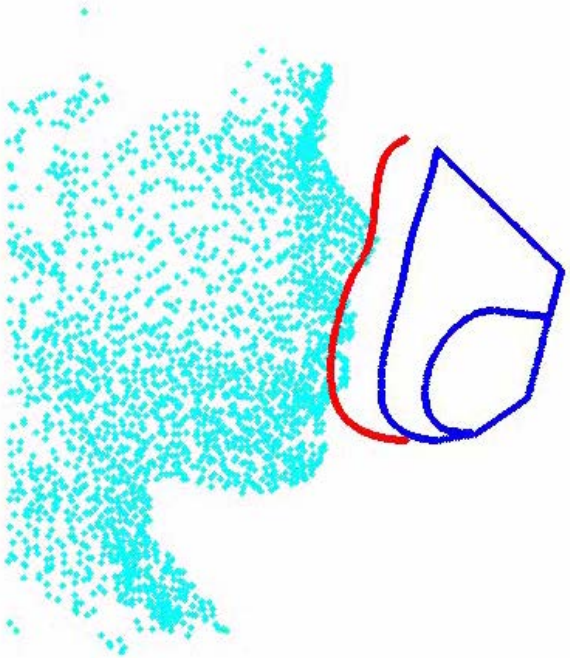
Scatter plot of landmarks

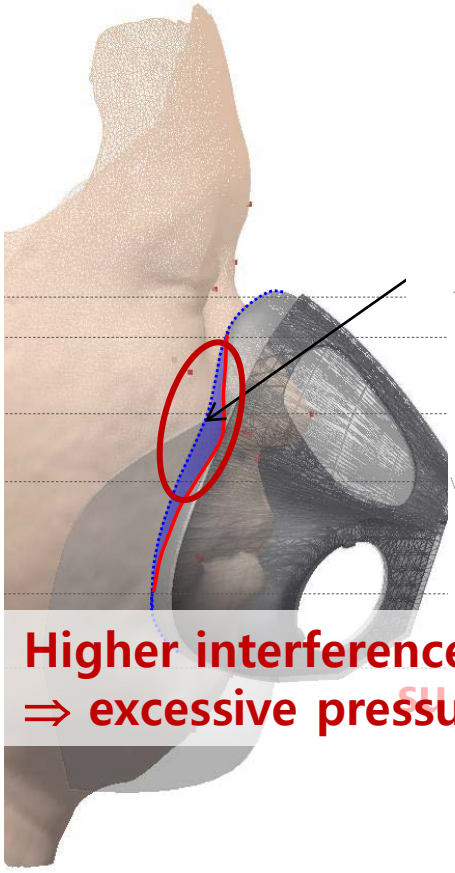


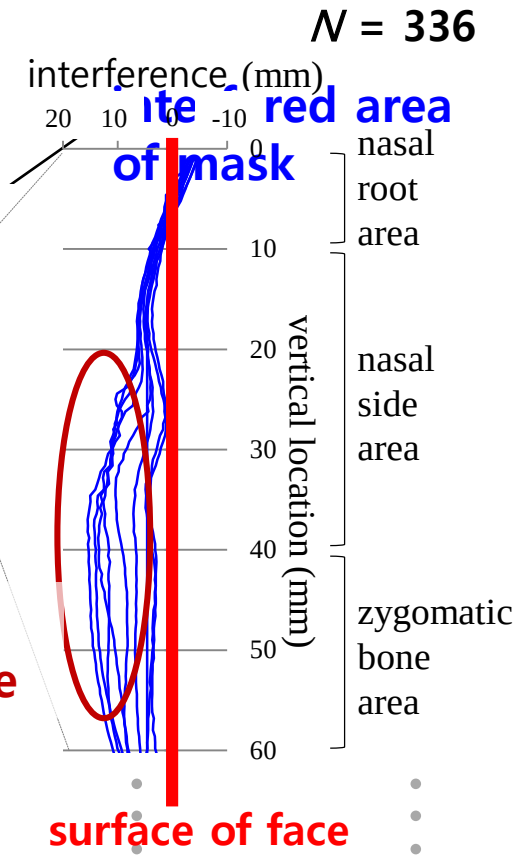
design of 3-size earphone hook

Design Based on Virtual Fit Analysis: Pilot Oxygen Mask

- Used various 3D face images (*N* = 336) and simplified OM CADs
- Virtual alignment and analysis
- Analyzed interference between face and mask







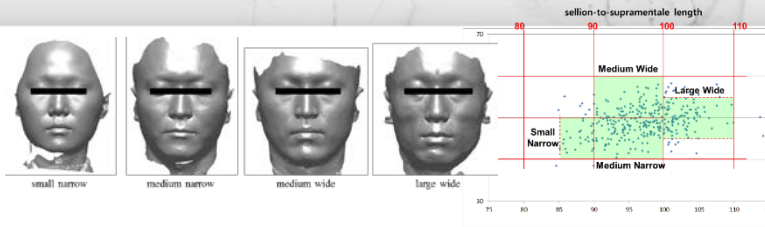
Iterative Design Improvement Through VF

S1. Design initial OM shape based on RFMs

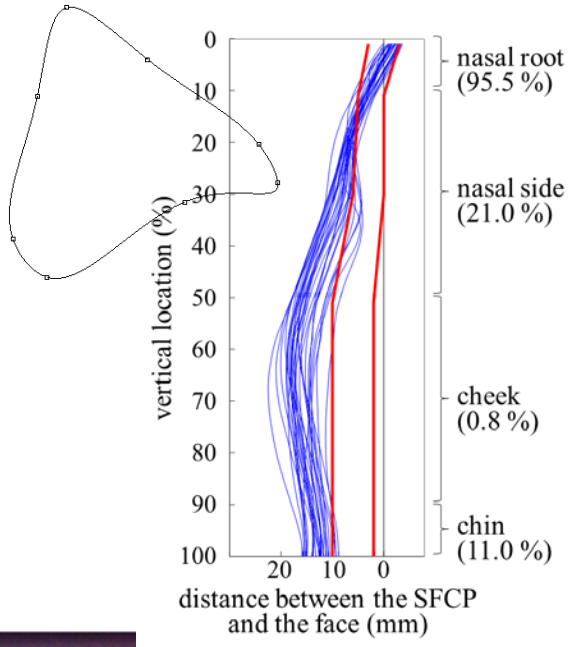
S2. Evaluation of design appropriateness through VFA

S3. Adjustment of OM shape

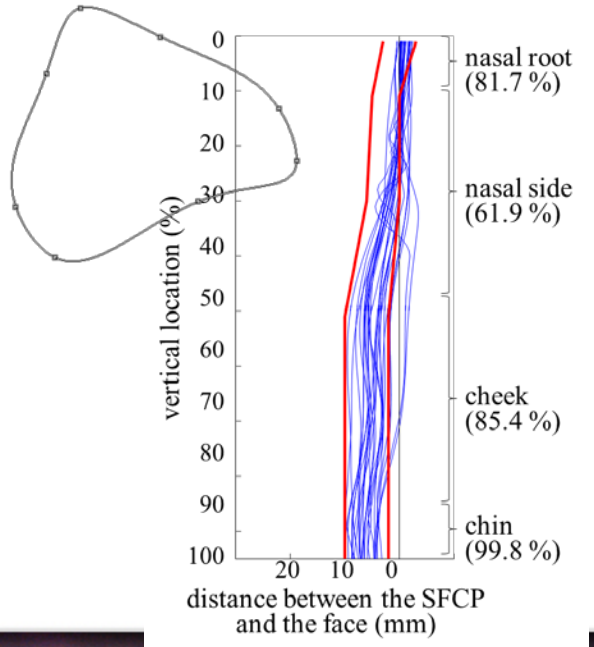
Iteration



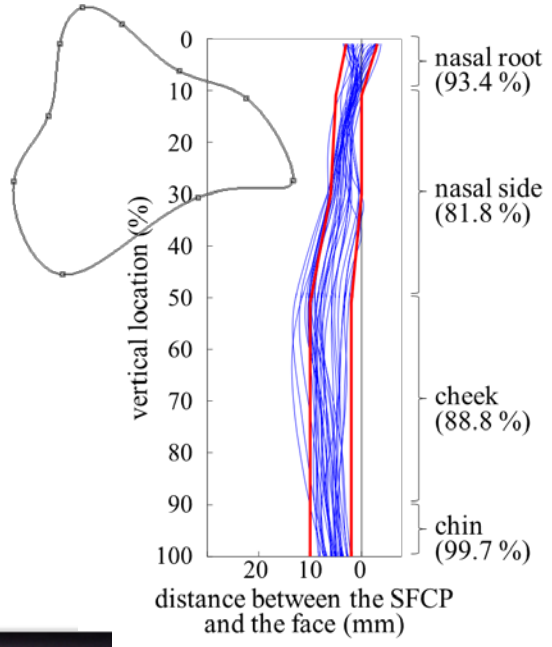
existing design
(mean accommodation: 32%)



initial design
(MA: 82%)



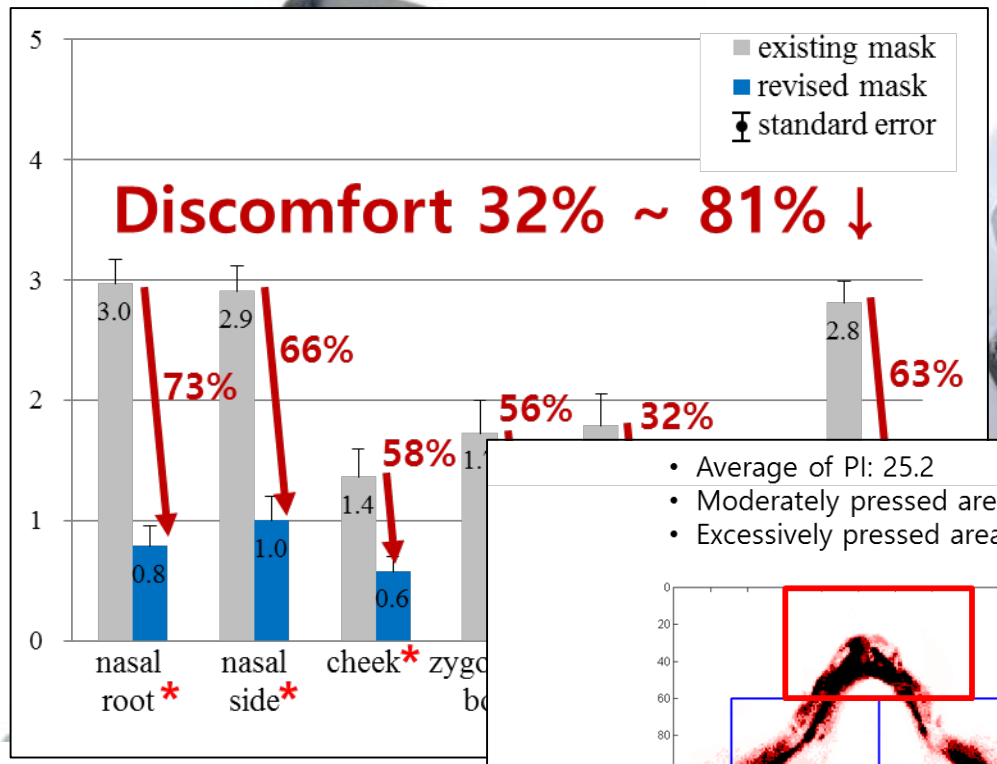
final design
(MA: 91%)



Comparison of OM Shape

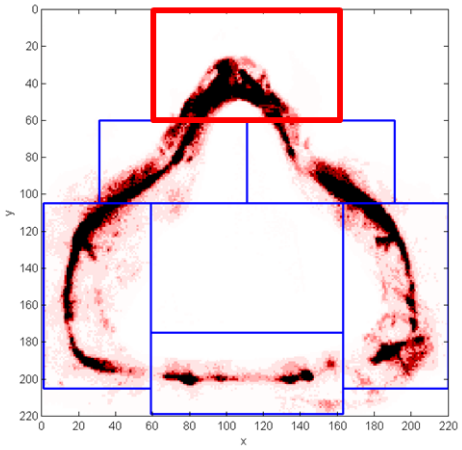
Existing mask

Revised mask



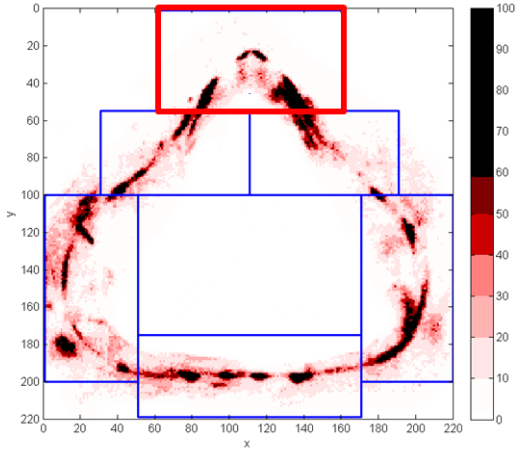
Comfortably enclosed the nasal area of pilot to prevent oxygen leakage

- Average of PI: 25.2
- Moderately pressed area: 948 px
- Excessively pressed area: 476 px



Existing mask (size: small narrow)

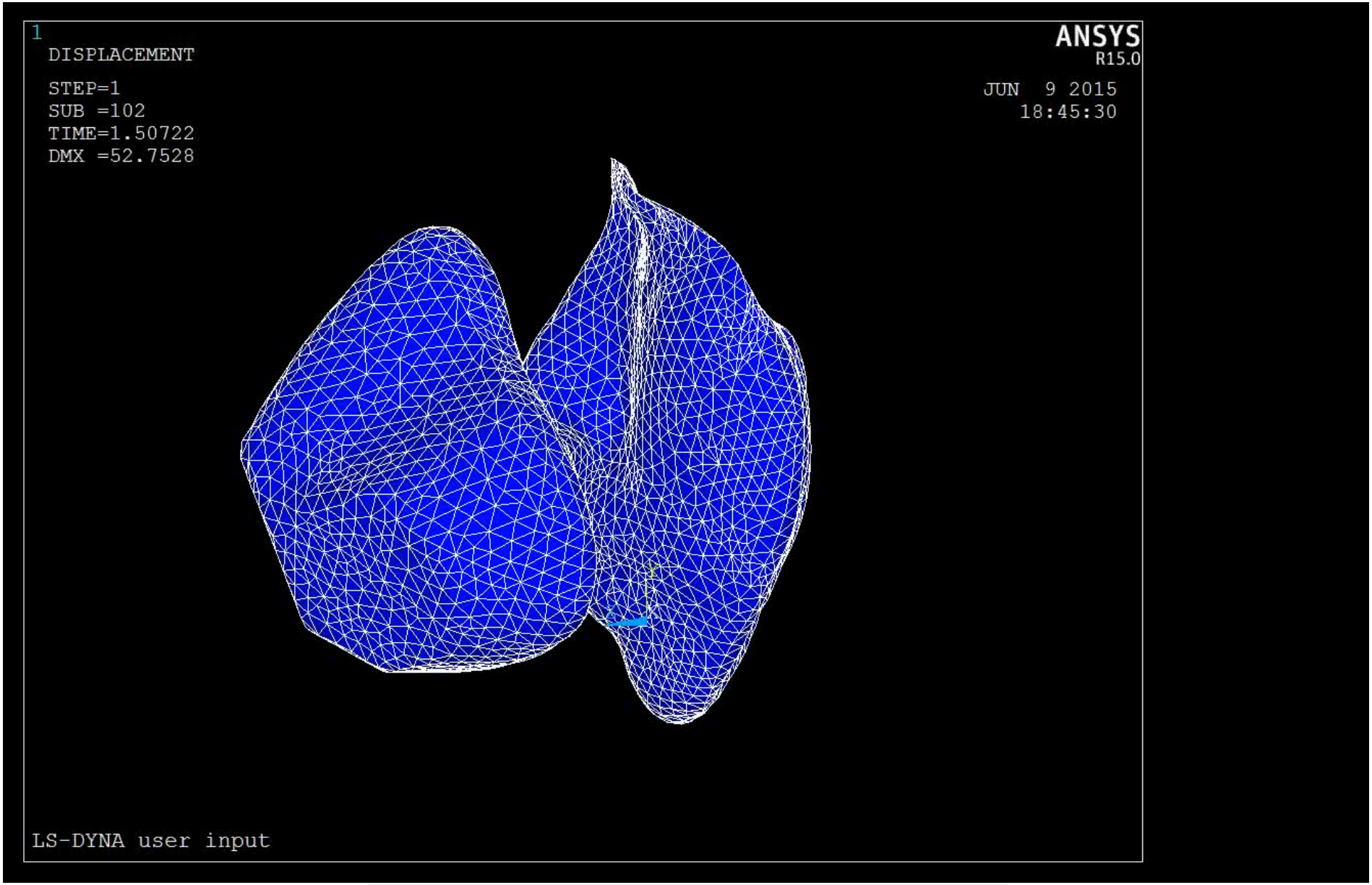
- Average of PI: 10.0 **(60% ↓)**
- Moderately pressed area: 170 px **(82% ↓)**
- Excessively pressed area: 82 px **(83% ↓)**



Revised mask (size: medium wide)

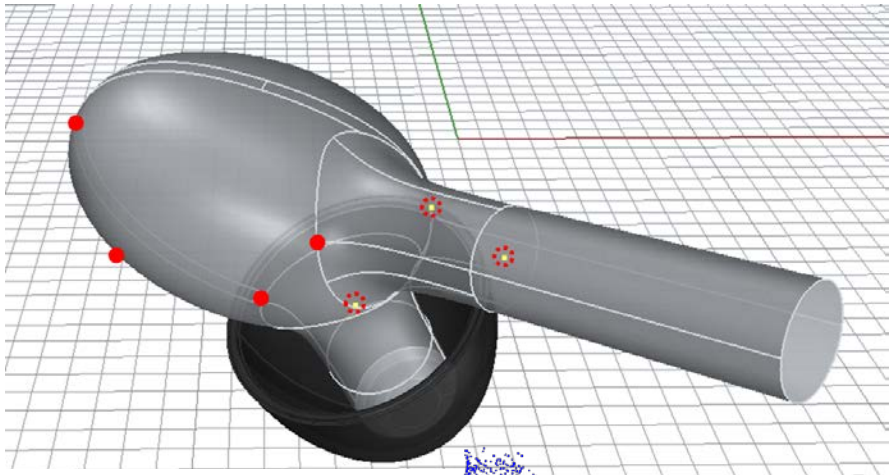
Contact pressure evaluation using pressure film

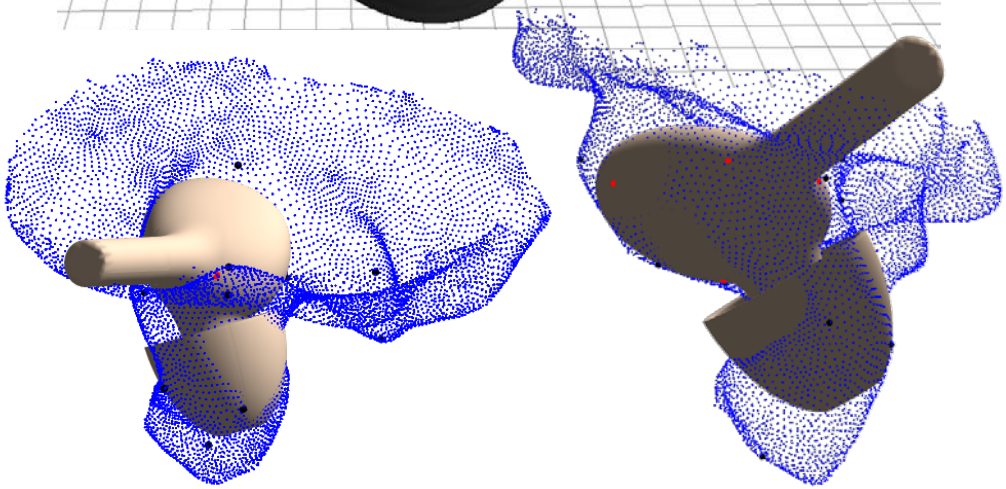
Pressure Estimation Based on Finite Element Analysis

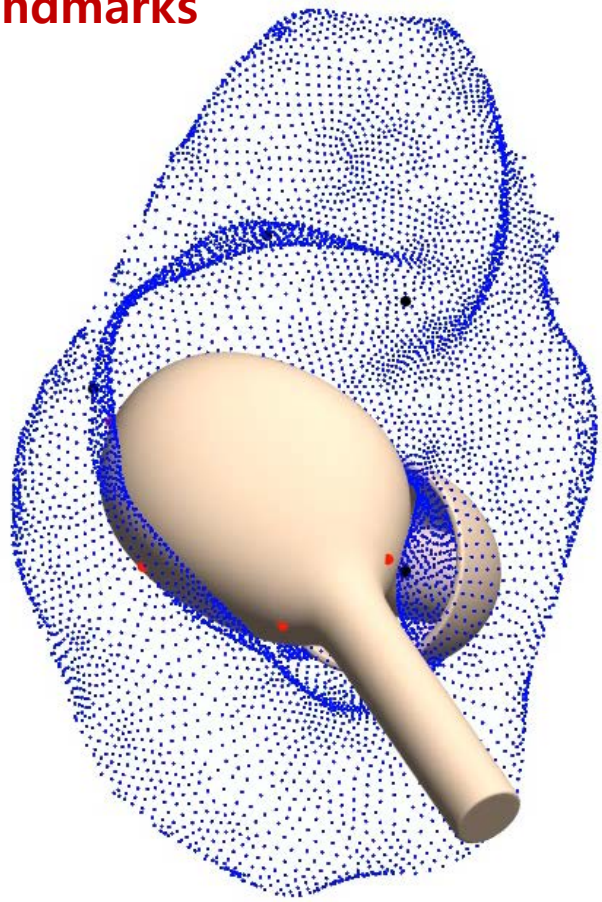


Design Based on Virtual Fit Analysis: Earphone

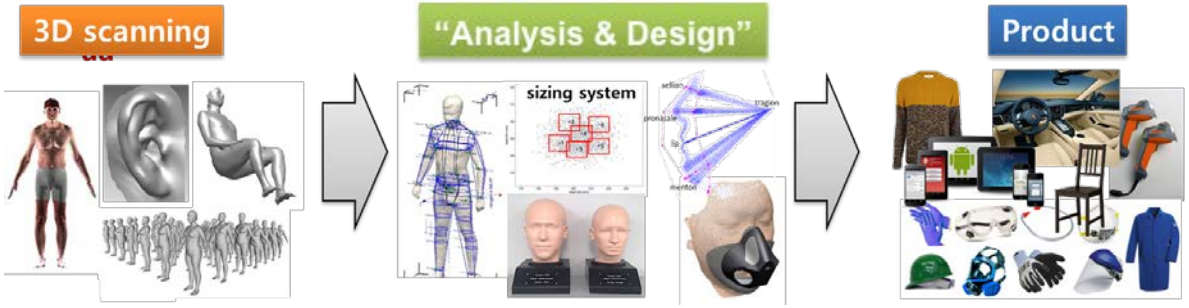
- **Fit simulation** to find **best shape and size** of earphone (N = 296)
- Based on **distance between ear and earphone landmarks**







Discussion: Research Issues in Product Design

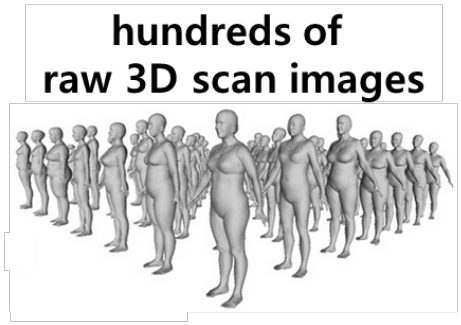


- **3D scanning**
  - Scanning in specialized posture
  - Skin deformation in motion (4D scanning) or by wearing/touching to product
  - 4D simulation based on template model
  - Efficiency for post-processing (editing, landmarking, measurement, feature extractio
  - Required more advance software for product design
- **Analysis & Design**
  - Analysis of deviation in complex dimensions (e.g., curvature, shape, area, volume)
  - Virtual fit simulation
    - ✓ Skin deformation
    - ✓ Posture change in product usage
    - ✓ Pressure/comfort estimation
    - ✓ Validation of simulation methods by experiment
  - Design methods
    - ✓ Optimal design (by virtual fit or FE simulation)
    - ✓ Parametric design
    - ✓ Rapid prototyping (3D printing)
  - Efficiency of analysis ⇒ development of computerized programs

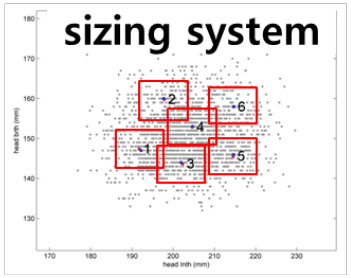
Discussion: Development of Computerized Systems

- For **easy and convenient analyses** to **product designers**

Designer



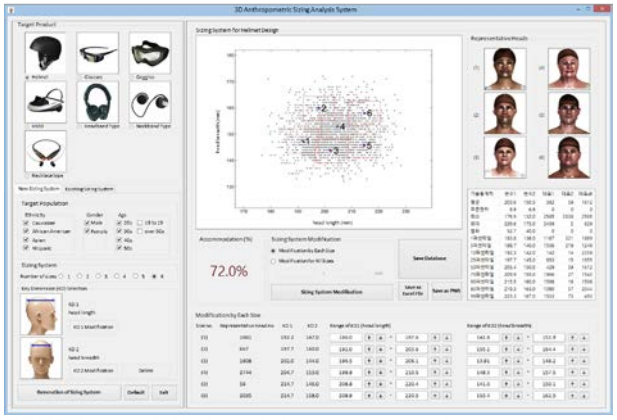
Vs.



RHMs

Designer

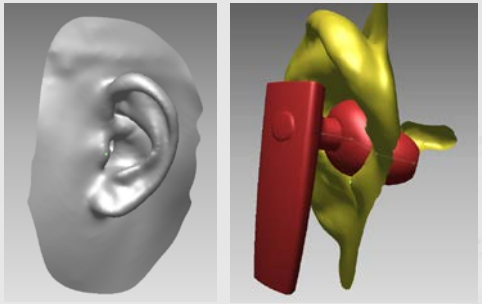
Computerized programs for sizing system and RHMs analyses



- **Virtual fit analysis**
- **Pressure estimation**
- **Comfort estimation**
- **Parametric design**

Thank you

CAESAR Head Data Improvement

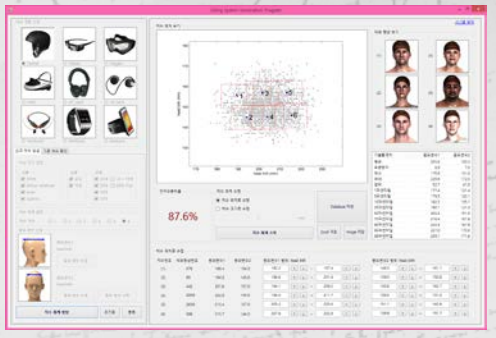


Ear Anthropometry

Hip Protector

Representative Models

Virtual Fit Analysis



Sizing Analysis System