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AI-Driven Ergonomic Headwear Customisation Study for the Chinese Population

Prof. Yan Luximon
PolyU UoA38

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Contents

AI-Driven Ergonomic Headwear Customisation Study for the Chinese Population

Descriptor

Amid the accelerating convergence of ergonomics, fashion and technology, the imperative for personalisation has emerged as a central determinant of customer satisfaction. Responding to this paradigm shift, this study investigates the collection, analysis and application of 3D head anthropometric data to advance the design of customised head-related products for the Chinese population. To address this need, an AI-driven ergonomic headwear customisation system was developed between 2021 and 2024 that integrates two main components: (1) advanced 3D facial landmarking and head-prediction algorithms, which yield precise headwear-related parameters to optimise fit and comfort and (2) automated parametric design techniques, facilitating the seamless customisation of ergonomic headwear products tailored to individual morphological parameters and user preferences.

Employing these methodologies, a comprehensive database of 3D head models for Chinese children and adults was established, a comfort prediction model for headwear products was constructed and an automatic, parametric headwear customisation system was implemented. The algorithms and models were rigorously validated through detailed applications to eyewear products.

The findings demonstrate that by integrating affordability, accuracy and automation, the system significantly enhances product fit and user experience, thereby redefining the standards of headwear customisation. This research received HKD 2.2 million in funding from the Laboratory for Artificial Intelligence in Design (Project Code: RP1-3), Innovation and Technology Fund, Hong Kong Special Administrative Region.

The research outcomes have been disseminated through five journal publications and one conference paper. The system has been recognised with one licensed patent and has garnered two international awards: the Silver Winner at the International Design Excellence Awards (IDEA) in 2023 and the Gold Medal with the Congratulations of the Jury at the 49th International Exhibition of Inventions of Geneva in 2024.

Personal Profile: Prof. Yan Luximon

Professor Yan Luximon's research focuses on the intersection of ergonomics and design innovation, with particular emphasis on 3D human body scanning, the application of 3D digital human modelling, computer-aided design (CAD) and artificial intelligence algorithms in the development of head- and face-related products. Her work adopts a multidisciplinary approach, drawing upon wearable product design, statistical and mathematical modelling and cross-cultural perspectives to advance understanding of human–product interaction, especially in relation to fit and comfort.

As a full professor and Associate Dean (research) at the School of Design at The Hong Kong Polytechnic University, Prof. Luximon leads the School Research Committee and provides strategic leadership and oversight for all research-related activities. She is also leader of the Asian Ergonomics Design Lab. As principal investigator, she has received six GRF projects and two ITF projects in the product- and interaction design–related research field. She has been awarded the PolyU School Award for Outstanding Achievement in Research and Scholarly Activities (Individual).

Research Questions

The main research question of this study was as follows:

How can 3D head anthropometric and comfort data be collected, analysed and leveraged to improve the design of customised head-related products for Chinese individuals?

The following were the sub-research questions:

1. What are the geometric variances and growth patterns of 3D anthropometry for Chinese heads?
2. How can subjectively perceived comfort be predicted based on objective head and product parameters?
3. How can 3D statistical anthropometric models and comfort information be used to establish product customisation?

Research Outputs

The research programme comprised the following outputs:

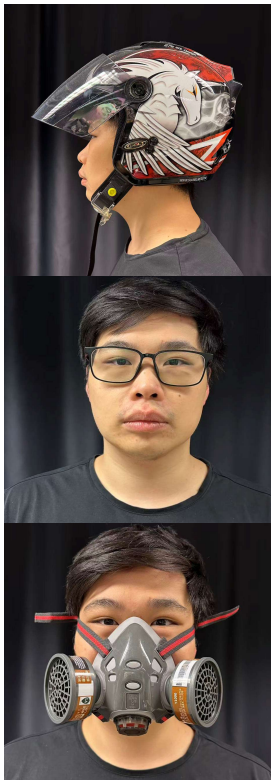
1. An automated headwear customisation system
2. Five journal papers
3. One conference paper
4. Prototypes

Research Field & Key References

The use of head-worn products – including glasses for vision correction [1], protective helmets [2], AR/VR/MR glasses and respirators – is becoming increasingly prevalent, particularly among children. Poorly fitting products can result in discomfort, safety hazards, serious medical issues and even fatal outcomes.

Accurate anthropometric data of the human head are essential for designing and customising high-quality head- or face-related products [3] – whether for mass production or individual use – to ensure optimal fit, safety, usability and comfort. Developing 3D geometric models that capture head growth patterns and variations based on age and gender is crucial for achieving a precise fit for a diverse population.

In addition, exploring perceptions of fit and comfort is another important aspect of designing ergonomic products [4]. However, the quantified relationships between 3D anthropometric and product parameters and users' perceptions of comfort in wearable product design remain insufficiently studied. Therefore, this study aimed to create a system combining 3D head anthropometric and comfort data to improve customised head-related products for the Chinese population.



Key references

1. W. H. Organization et al., World report on vision. (2019). https://www.who.int/publications/i/item/9789241516570
2. Kiplagat, S. J., & Steyl, T. (2016). Injury patterns and mortality rates of motorcycle-related head injuries in Kenya. East African Medical Journal, 93(1), 23-27.
3. Zhuang, Z., Bradtmiller, B., & Shaffer, R. E. (2007). New respirator fit test panels representing the current U.S. civilian work force. Journal of Occupational and Environmental Hygiene, 4(9), 647–659. https://doi.org/10.1080/15459620701497538
4. Chang, J., Jung, K., Kim, W., Moon, S. K., Freivalds, A., Simpson, T. W., & Baik, S. P. (2014). Effects of weight balance on a 3D TV shutter type glasses: Subjective discomfort and physical contact load on the nose. International Journal of Industrial Ergonomics, 44(6), 801–809. https://doi.org/10.1016/j.ergon.2014.10.005

Research Methods, Prototypes & Materials

There were three milestones for this study.

- **Milestone 1: Establishing large-scale 3D head models for the Chinese population**

  (Sub-research question 1)

  - Build 3D head models for Chinese children and adults based on age and gender
  - Analyse the shape variances and growth patterns

- **Milestone 2: Quantifying comfort perception for headwear products**

  (Sub-research question 2)

  - Analyse the product features using eyewear as an example
  - Study the relationship between perceptions of comfort and product features

- **Milestone 3: Customising automated parametric and ergonomic headwear**

  (Sub-research question 3)

  - Analyse the method for product parameterisation using helmets and eyewear as examples
  - Build the headwear customisation system

Research Methods – Milestone 1

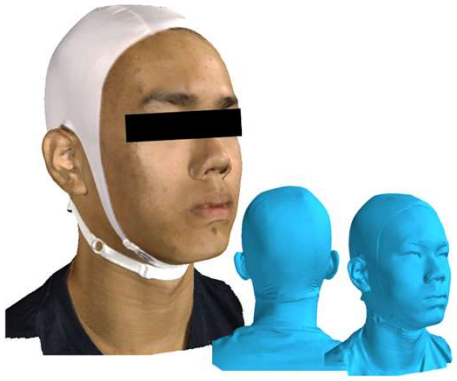
Establishing Large-Scale 3D Head Models for the Chinese Population

First, a comprehensive head model dataset comprising 1763 adults and 793 children from China was developed. The age and gender information for all participants is summarised here.

3D scanners, including the Artec Eva 3D and Cyberware 3030 3D colour scanners, were used to collect all the data. During scanning, a tight latex cap was used to reduce false data points caused by the model's hairstyle. The data collection process was safe and presented no known risks.

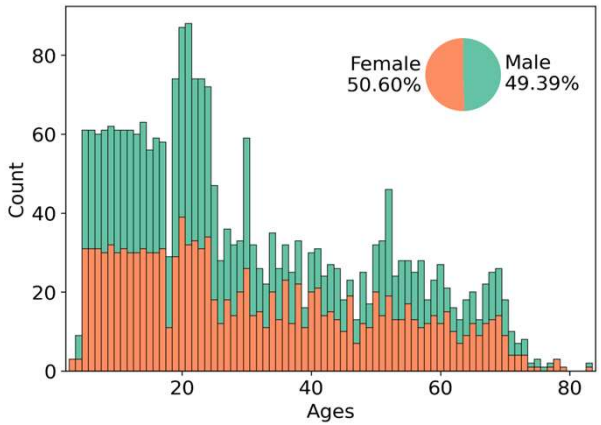
This dataset served as the basis for constructing statistical shape models that could accurately capture the variations in head shapes.

The details of the dataset are published in the following papers.



Male example

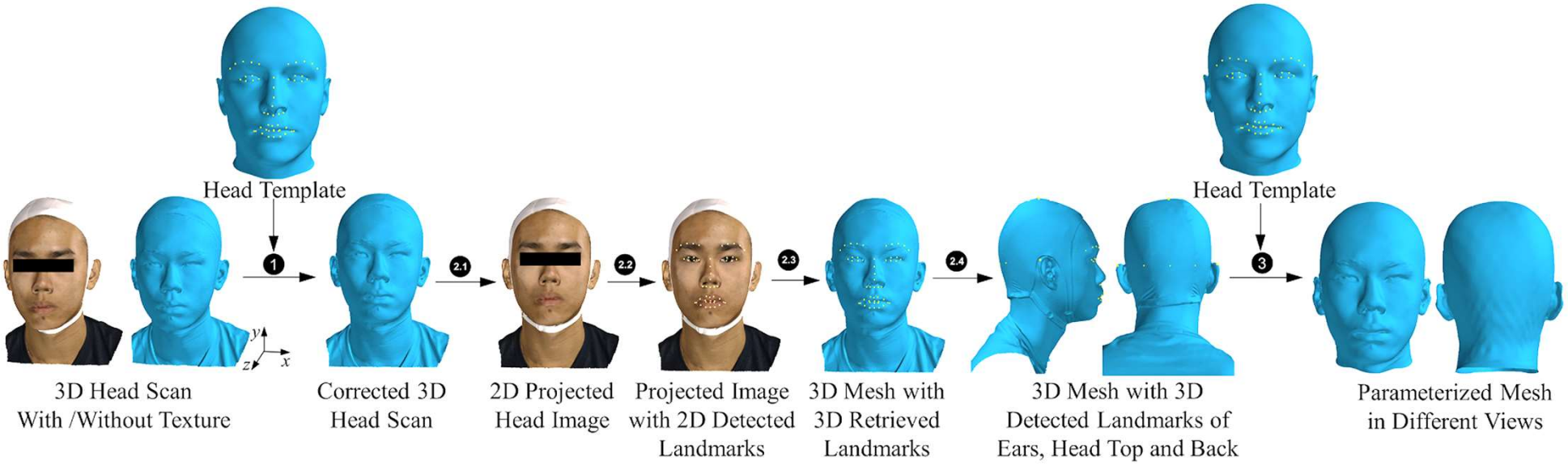
Female example



- Zhang, J., Iftikhar, H., Shah, P., & Luximon, Y.* (2022). Age and sex factors integrated 3D statistical models of adults' heads. International Journal of Industrial Ergonomics, 90(103321), 1–13. https://doi.org/10.1016/j.ergon.2022.103321
- Zhang, J., Fu, F., Shi, X., & Luximon, Y.* (2023). Modeling 3D geometric growth patterns and variations of children's heads. Applied Ergonomics, 108(103933), 1–11. https://doi.org/10.1016/j.apergo.2022.103933

Research Methods – Milestone 1

Establishing Large-Scale 3D Head Models for the Chinese Population



A head-parameterisation process was developed to transfer the original 3D head-scan data to a parameterised mesh model for calculating statistical variations. The overall process consisted of three main steps: (1) head-scan pose correction, (2) facial-landmark detection and (3) head-mesh registration. In Step 2, there were four sub-steps: (1) head-scan projection, (2) 2D facial-landmark detection, (3) 3D facial landmark retrieval in the face region and (4) 3D landmark detection in the ear, head-top and back regions.

The details of the parameterization method are presented in the following paper:

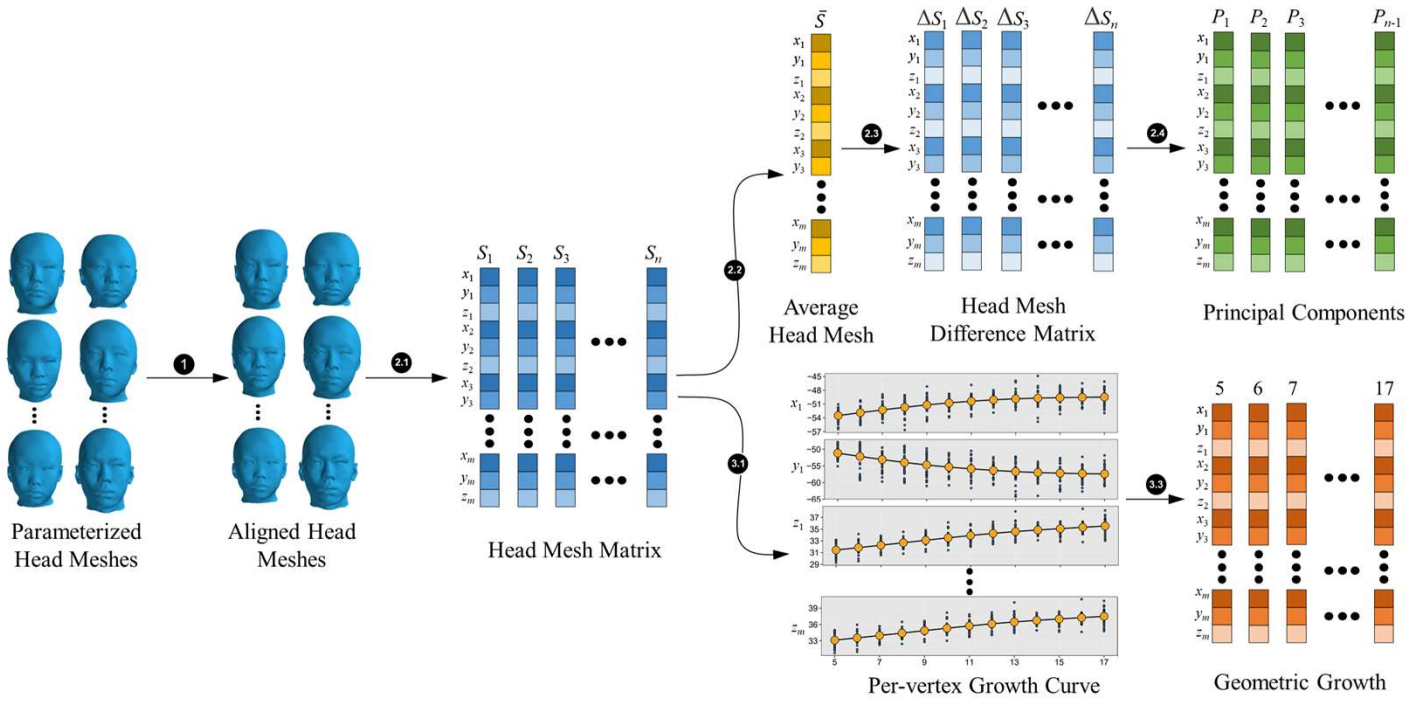
- Zhang, J., Fu, F., Shi, X., & Luximon, Y.* (2023). Modeling 3D geometric growth patterns and variations of children's heads. Applied Ergonomics, 108(103933), 1–11. https://doi.org/10.1016/j.apergo.2022.103933

Research Methods – Milestone 1

Establishing Large-Scale 3D Head Models for the Chinese Population

An automatic framework for modelling the 3D geometric growth patterns and gender-specific variations of adults' and children's heads was proposed. This framework provides valuable references for head- and face-related product designs for children, including the development of a more accurate sizing system and improvements in product fit and function.

Head-pose alignment, head-variation and head-growth analysis process:
(1) Head-mesh alignment using generalised Procrustes analysis (GPA), (2) head-variation analysis using principal component analysis (PCA) and (3) head-growth analysis using the generalised per-vertex-based lambda–mu–sigma (LMS) method.



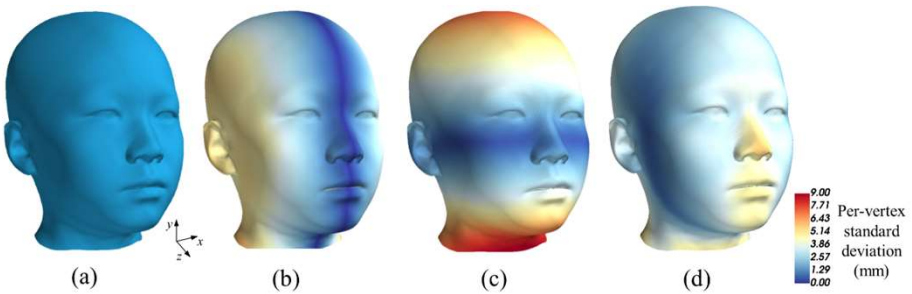
The details of the 3D head-variation modelling method are presented in the following paper:

- Zhang, J., Fu, F., Shi, X., & Luximon, Y.* (2023). Modeling 3D geometric growth patterns and variations of children's heads. Applied Ergonomics, 108(103933) 1–11. https://doi.org/10.1016/j.apergo.2022.103933

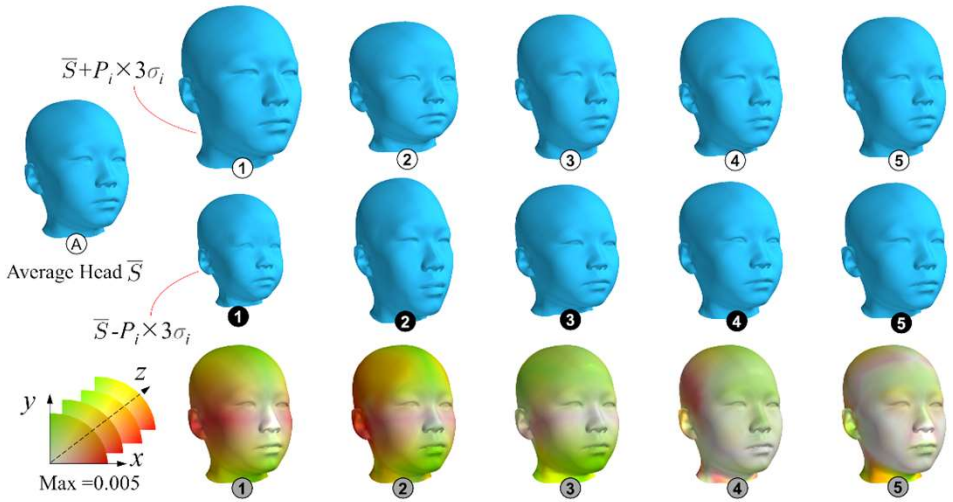
Research Methods – Milestone 1

Establishing Large-Scale 3D Head Models for the Chinese Population

Results for children aged < 18 – 3D statistical shape model: Global model



Global basic statistics of head meshes.
(a) Average head mesh
(b) Per-vertex standard deviation along the x-axis
(c) Per-vertex standard deviation along the y-axis
(d) Per-vertex standard deviation along the z-axis



Average head model with the first five principal components

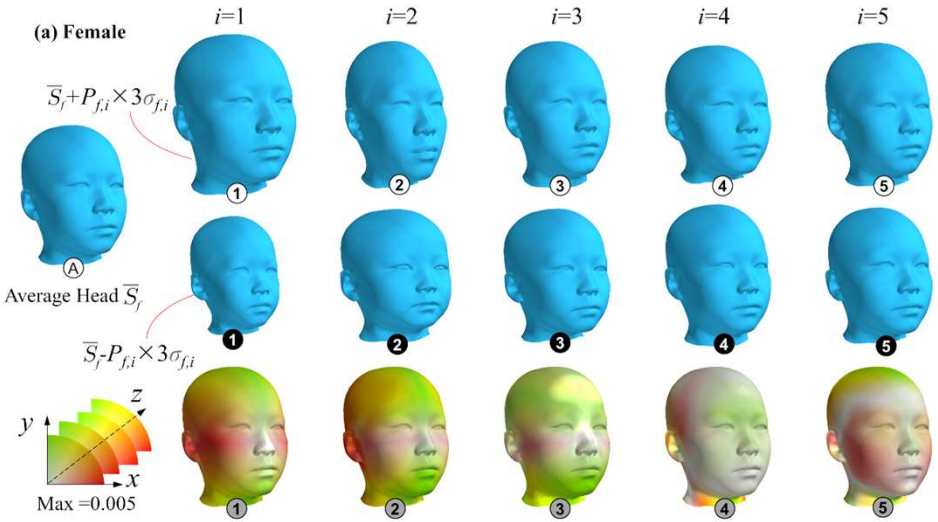
The results of the 3D head-geometric variances and growth patterns are presented in the following paper:

- Zhang, J., Fu, F., Shi, X., & Luximon, Y.* (2023). Modeling 3D geometric growth patterns and variations of children's heads. Applied Ergonomics, 108(103933), 1–11. https://doi.org/10.1016/j.apergo.2022.103933

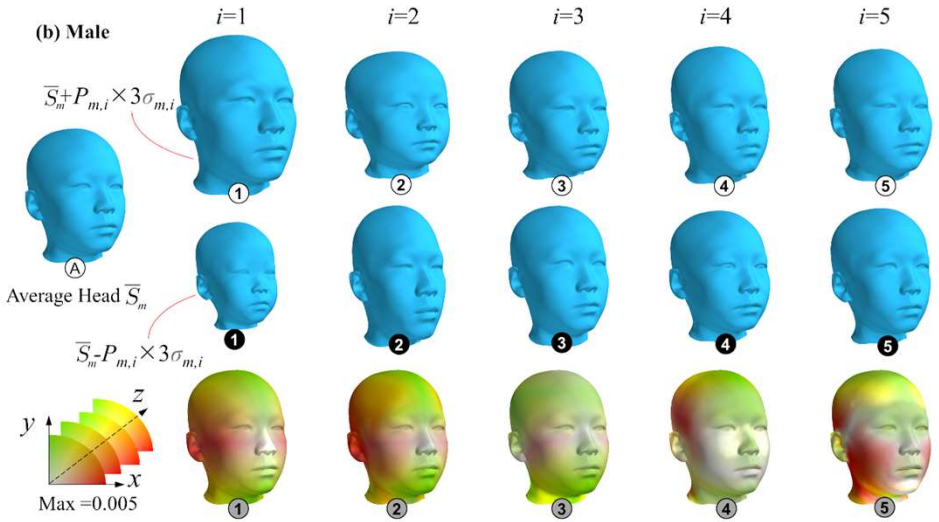
Research Methods – Milestone 1

Establishing Large-Scale 3D Head Models for the Chinese Population

Results for children aged < 18 – Subclass models based on gender



Average female head with the first five principal components



Average male head with the first five principal components

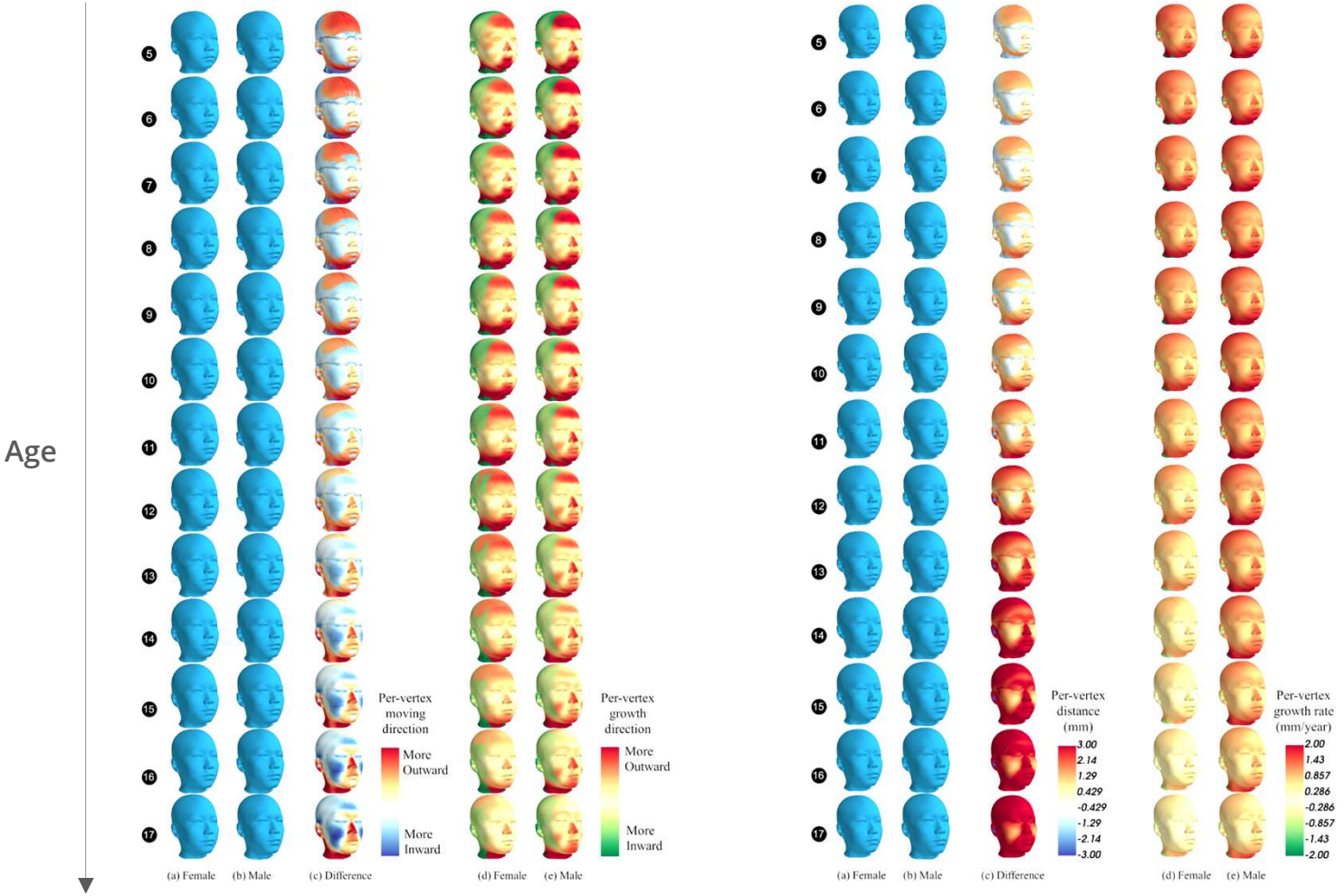
The results of the 3D head-geometric variances and growth patterns are presented in the following paper:

- Zhang, J., Fu, F., Shi, X., & Luximon, Y.* (2023). Modeling 3D geometric growth patterns and variations of children's heads. Applied Ergonomics, 108(103933), 1–11. https://doi.org/10.1016/j.apergo.2022.103933

Research Methods – Milestone 1

Establishing Large-Scale 3D Head Models for the Chinese Population

Results for growth pattern based on age and gender



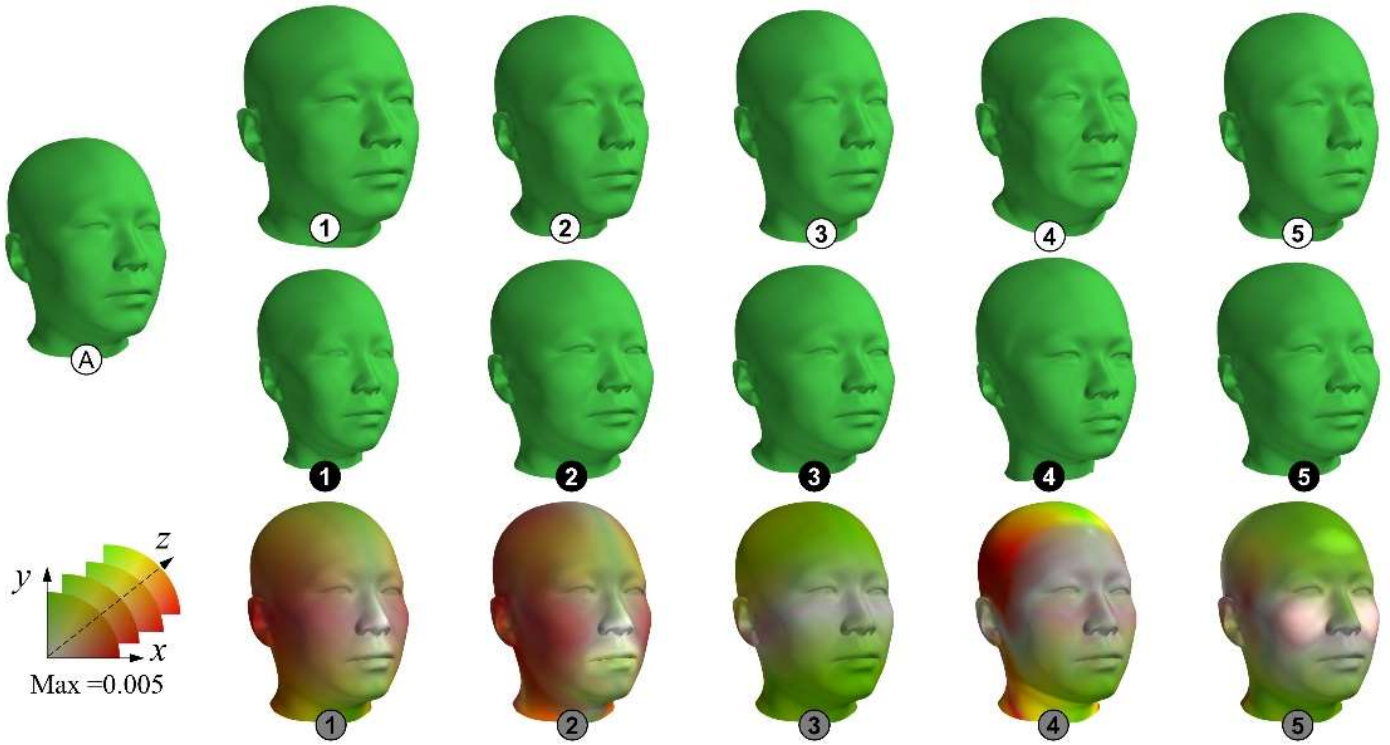
The results of the 3D head-geometric variances and growth patterns are presented in the following paper:

- Zhang, J., Fu, F., Shi, X., & Luximon, Y.* (2023). Modeling 3D geometric growth patterns and variations of children's heads. Applied Ergonomics, 108(103933), 1–11. https://doi.org/10.1016/j.apergo.2022.103933

Research Methods – Milestone 1

Establishing Large-Scale 3D Head Models for the Chinese Population

Results for adults aged ≥ 18 – 3D statistical shape model: Global model



Average head model with the first five principal components

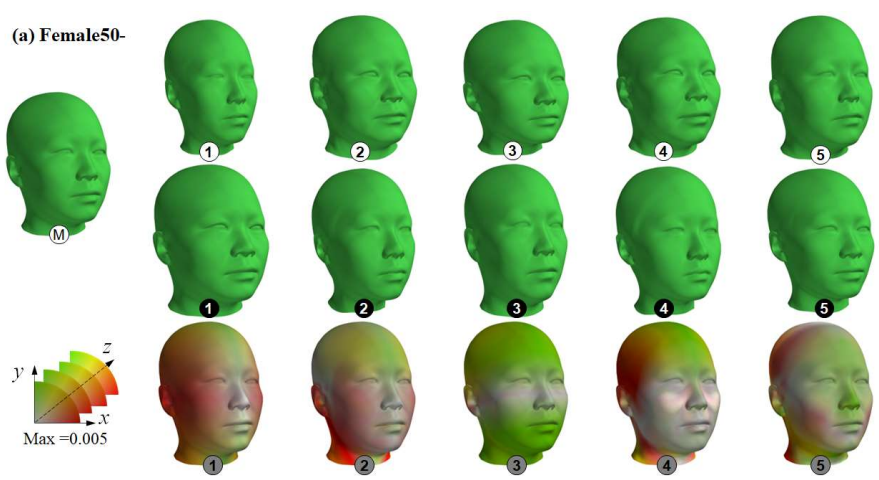
The results of the 3D head geometric variances and growth patterns are presented in the following paper:

- Zhang, J., Iftikhar, H., Shah, P., & Luximon, Y.* (2022). Age and sex factors integrated 3D statistical models of adults' heads. International Journal of Industrial Ergonomics, 90(103321), 1–13. https://doi.org/10.1016/j.ergon.2022.103321

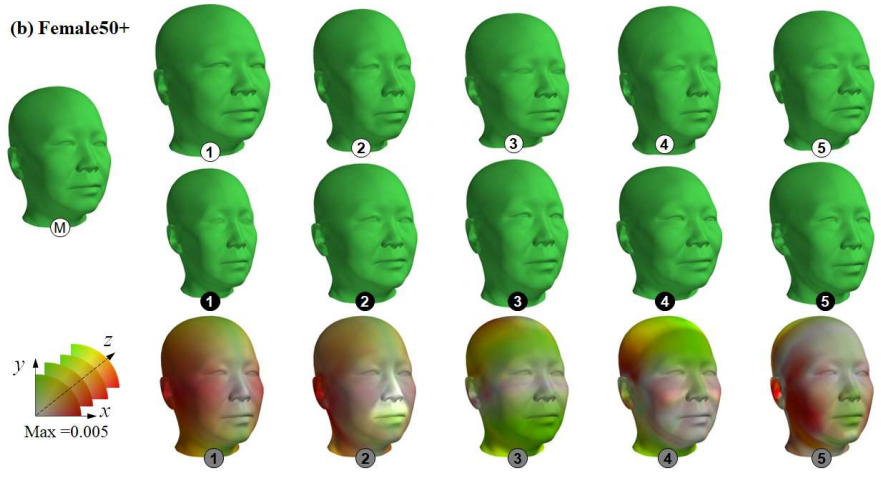
Research Methods – Milestone 1

Establishing Large-Scale 3D Head Models for the Chinese Population

Results for female adults – 3D statistical shape model: Subclass models based on age



18 ≤ age < 50
Average head model with the first five principal components



Age ≥ 50
Average head model with the first five principal components

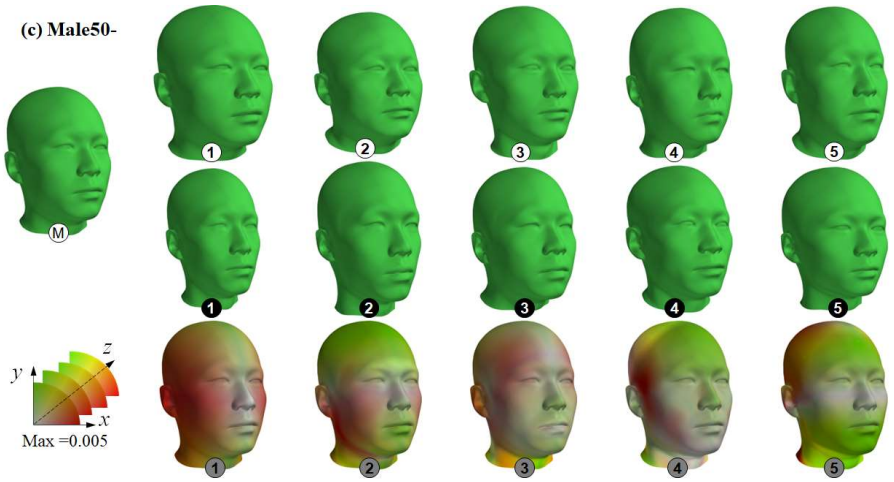
The results of the 3D head geometric variances and growth patterns are presented in the following paper:

- Zhang, J., Iftikhar, H., Shah, P., & Luximon, Y.* (2022). Age and sex factors integrated 3D statistical models of adults' heads. International Journal of Industrial Ergonomics, 90(103321), 1–13. https://doi.org/10.1016/j.ergon.2022.103321

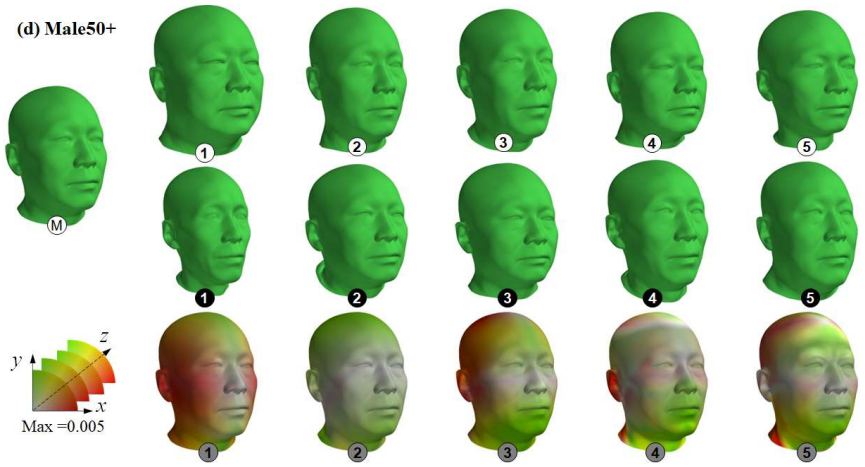
Research Methods – Milestone 1

Establishing Large-Scale 3D Head Models for the Chinese Population

Results for male adults – 3D statistical shape model: Subclass models based on age



18 ≤ age < 50
Average head model with the first five principal components



Age ≥ 50
Average head model with the first five principal components

The results of the 3D head geometric variances and growth patterns are presented in the following paper:

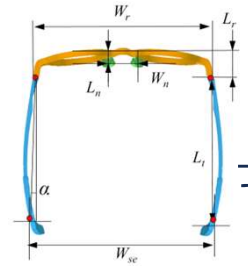
- Zhang, J., Iftikhar, H., Shah, P., & Luximon, Y.* (2022). Age and sex factors integrated 3D statistical models of adults' heads. International Journal of Industrial Ergonomics, 90(103321), 1–13. https://doi.org/10.1016/j.ergon.2022.103321

Research Methods – Milestone 2

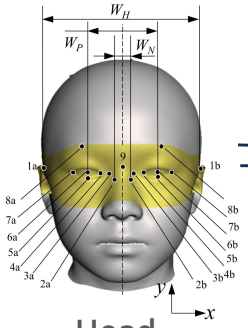
Quantifying Comfort Perception for Headwear Products

Comfort Prediction Model: Using eyeglasses as an example

Children's comfort perceptions of eyeglasses were examined using two variables – nose-pad width and temple-clamping force – and quantified linkage models between subjective human perceptions and objective 3D anthropometric and product parameters were established.



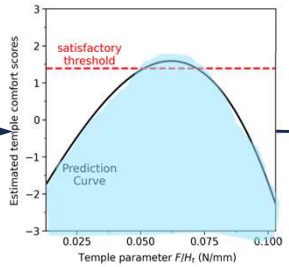
Eyeglasses Parameters



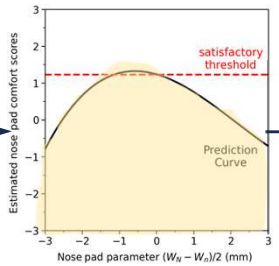
Head Parameters

Temple clamping force

Nose pads width scale factor



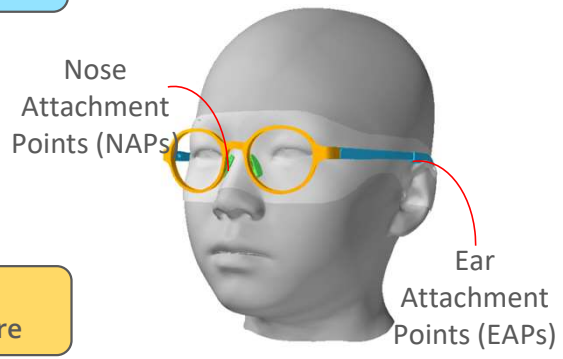
Temple-to-Comfort Trendline



Nose Pads-to-Comfort Trendline

Perceived comfort score

Perceived comfort score



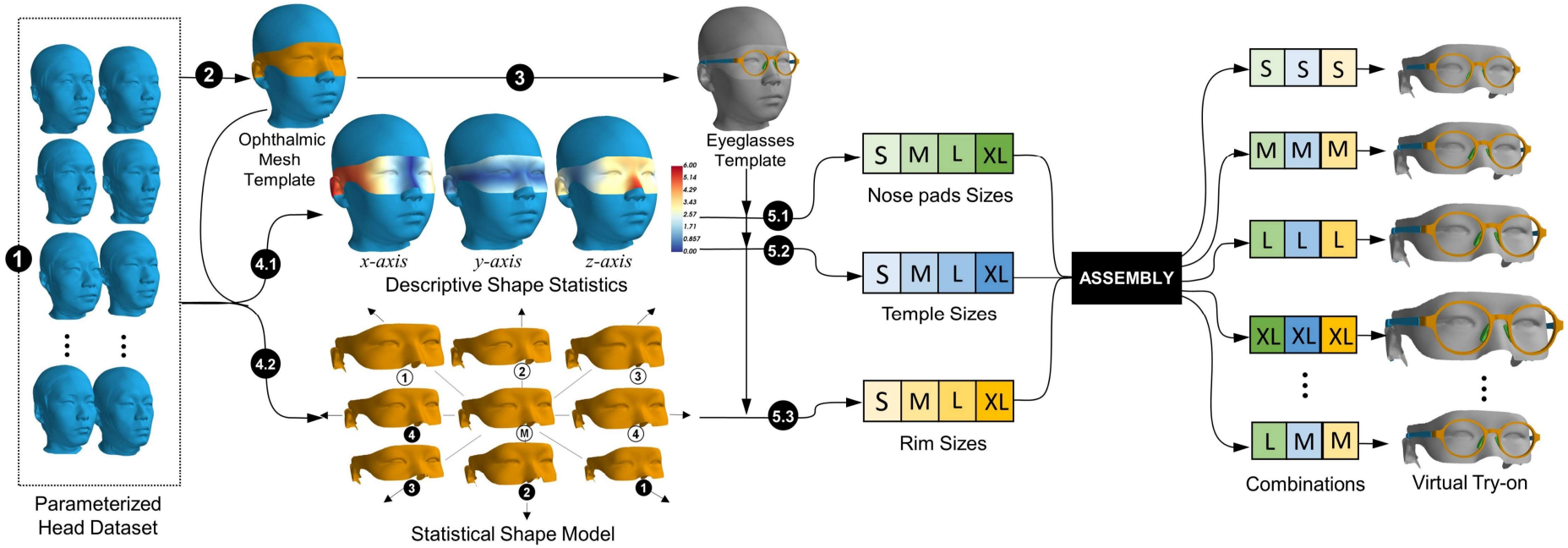
The comfort prediction model and measurements are presented in the following papers:

- Zhang J., Chen J., Chen L., & Luximon, Y.* (2023). A novel temple clamping force measurement method for eyeglasses design. Proceedings of the 14th International Conference on Applied Human Factors and Ergonomics (AHFE 2023) and the Affiliated Conferences (July 20–24, 2023). New York, USA. http://doi.org/10.54941/ahfe1003305
- Zhang J., Chen J., Fu F., & Luximon Y.* (2023). A 3D anthropometry-based quantified comfort model for children's eyeglasses design. Applied Ergonomics, 112(104054), 1–14. https://doi.org/10.1016/j.apergo.2023.104054

Research Methods – Milestone 3

Customising Automated Parametric and Ergonomic Headwear

Combining the results from Milestones 1 and 2, an eyeglass-sizing system was established for customisation.



Overview of a comfort-orientated and assembly-guided approach for developing an eyeglasses-sizing system. The process consists of five main steps: parameterised head dataset collection (1), ophthalmic template modelling (2), eyeglasses template modelling (3), geometric variance analysis (4) including descriptive statistical analysis (4.1) and statistical model creation (4.2), and components' sizes including nose pads (5.1), temple (5.2) and rims (5.3). From the descriptive shape statistics (4.1), per-vertex standard deviations along different axes were computed. From statistical shape model (4.2), the first principal component (PC) (① and ❶) with different loadings and average shape M was used to generate representative shapes. Four sizes – small, medium, large and extra-large – are denoted as S, M, L and XL, respectively.

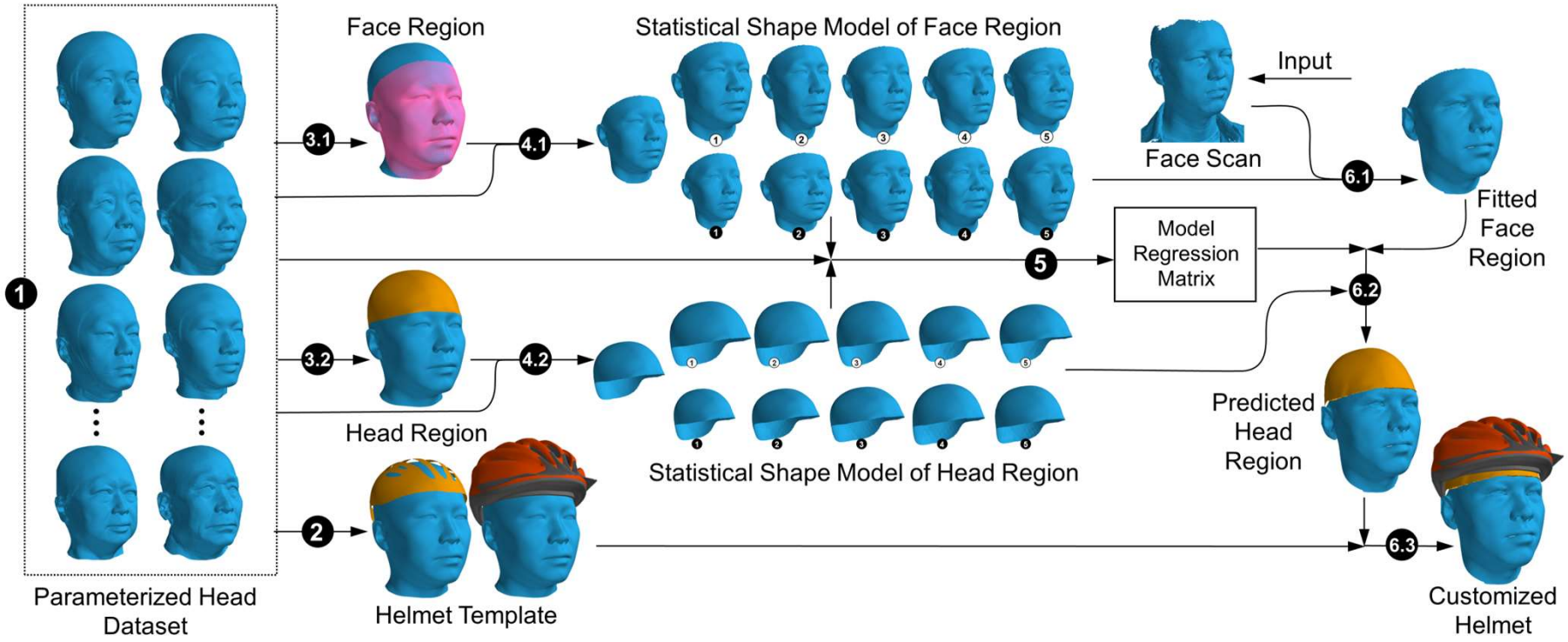
The results were published in the following paper:

Zhang, J., Luximon, Y.,* & Chen, L. (2024). Size children's eyeglasses: An assembly-guided and comfort-oriented optimization approach based on 3D statistical ophthalmic modeling. Advanced Engineering Informatics, 59(102266). https://doi.org/10.1016/j.aei.2023.102266

Research Methods – Milestone 3

Customising Automated Parametric and Ergonomic Headwear

Using a helmet as another example to validate the customisation system based on the 3D head-prediction algorithm.



Overview of the proposed 3D head-prediction algorithm from incomplete scans for helmet customisation. This method can be used to customise a helmet based on an individual face scan. The main workflow of 3D head-prediction and helmet-customisation consists of the following steps: parameterised head dataset collection (1); helmet-template modelling (2); head-template region segmentation (3), including face (3.1) and head region (3.2) segmentation; establishment of the statistical shape model (SSM) (4), including SSMs of face and head regions; model regression matrix calculation (5); and individual helmet customisation (6).

The results were published in the following paper:

Zhang, J., Luximon, Y.,* Shah, P., Zhou, K., & Li, P. (2022). Customize my helmet: A novel algorithmic approach based on 3D head prediction. Computer-Aided Design, 150(103271), 1–10. https://doi.org/10.1016/j.cad.2022.103271

Research Outcomes, Findings & Further Research

Comprehensive Dataset

A comprehensive dataset was compiled, comprising 1763 adults and 793 children from China. This dataset effectively addresses the deficiency of child subjects in existing 3D face datasets. It provides essential anthropometric knowledge for various head- and face-related applications, including product design, physical head reconstruction, craniofacial syndrome diagnosis and surgical planning and evaluation. Further research may be extended to younger children to complete the dataset.

Headwear Comfort Prediction Model

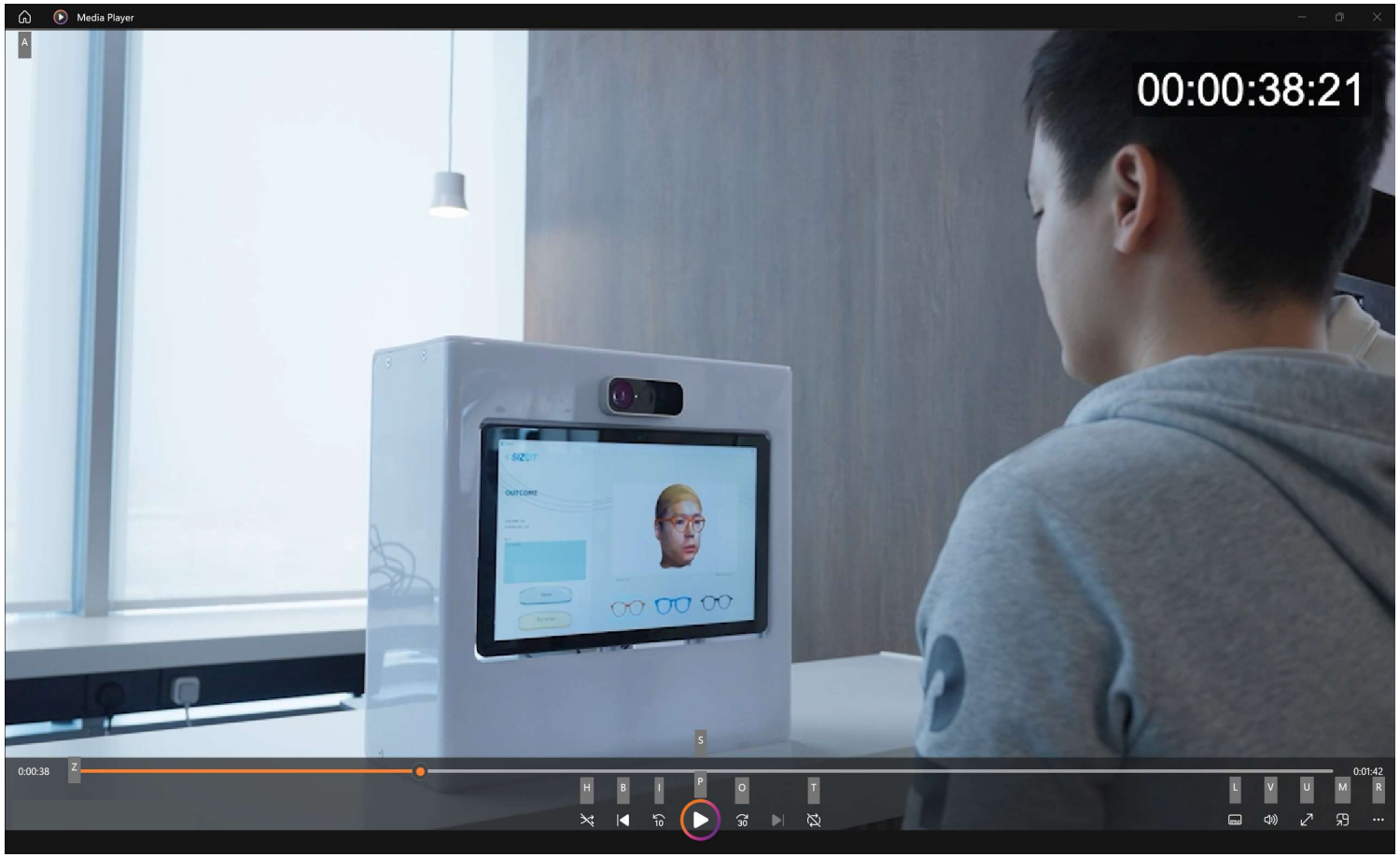
This research led to the construction of a model for predicting the perceived comfort of children's eyeglasses. This model serves as a valuable tool for guiding the design process of personalised and mass-customised eyeglasses. Additionally, it enables the evaluation and optimisation of existing eyeglasses to enhance wearer comfort. Other headwear products could be considered in future research.

Parametric and Ergonomic Headwear Customisation Framework

A parametric and ergonomic headwear customisation framework was developed by integrating accurate 3D facial landmarking and automated parametric design techniques. This framework opens new possibilities for customised headwear in diverse applications and enhances the overall user experience. Experimental results demonstrated the effectiveness and superiority of the algorithms developed. Through this system, users can enjoy personalised and well-fitted headwear, particularly in the case of eyeglasses and helmets. More headwear products could be tested to enable wider application in the future.

Research Dissemination

The Automated Headwear Customisation System



This video demonstrates how this automatic headwear customisation system works using an eyewear design example. A similar process can be applied to other types of headwear, such as helmets. The video can be found at https://www.youtube.com/watch?v=o93sNnSWyrg.

Research Dissemination

Journal and Conference Papers

1. Zhang, J., Iftikhar, H., Shah, P., & Luximon, Y.* (2022). Age and sex factors integrated 3D statistical models of adults' heads. International Journal of Industrial Ergonomics, 90(103321), 1–13. https://doi.org/10.1016/j.ergon.2022.103321

2. Zhang, J., Fu, F., Shi, X., & Luximon, Y.* (2023). Modeling 3D geometric growth patterns and variations of children's heads. Applied Ergonomics, 108(103933), 1–11. https://doi.org/10.1016/j.apergo.2022.103933

3. Zhang, J., Chen, J., Fu, F., & Luximon, Y.* (2023). A 3D anthropometry-based quantified comfort model for children's eyeglasses design. Applied Ergonomics, 112(104054), 1–14. https://doi.org/10.1016/j.apergo.2023.104054

4. Zhang, J., Chen, J., Chen, L., & Luximon, Y.* (2023). A novel temple clamping force measurement method for eyeglasses design. Proceedings of the 14th International Conference on Applied Human Factors and Ergonomics (AHFE 2023) and the Affiliated Conferences (July 20–24, 2023). New York, USA. http://doi.org/10.54941/ahfe1003305

5. Zhang, J., Luximon, Y.,* & Chen, L. (2024). Size children's eyeglasses: An assembly-guided and comfort-oriented optimization approach based on 3D statistical ophthalmic modeling. Advanced Engineering Informatics, 59(102266). https://doi.org/10.1016/j.aei.2023.102266

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Research Dissemination

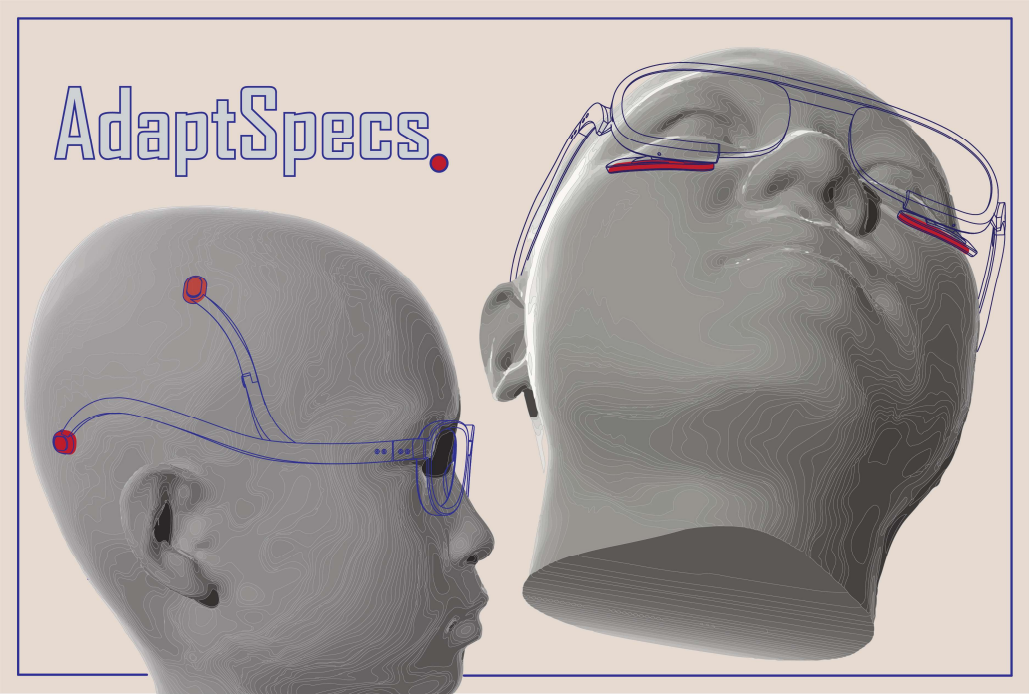
Prototypes: Eyewear Designs for Individuals

These eyewear prototypes were created in 2023 using the parametric headwear customisation system and were validated with users in an evaluation experiment.

Research Dissemination

Awards

AdaptSpecs - Fitted Frames for the Disfigured: Design Credits



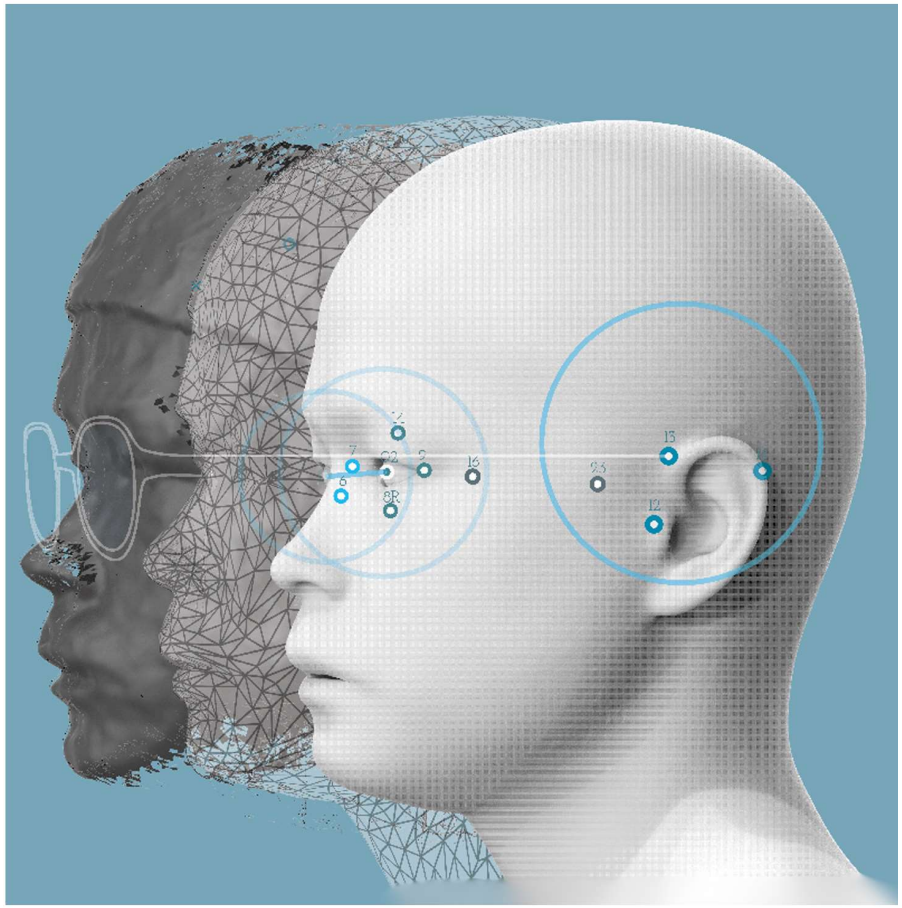
The frame was designed for people who have difficulty wearing regular eyewear, which relies on the nasal bridge and ears as support points. It was created based on the head-modelling method and designed to fit individual users, then 3D printed for parameterisation.

This design received an international design award – the Silver Award at the International Design Excellence Awards 2023, presented by the Industrial Designers Society of America.

Research Dissemination

Awards

AI-Driven Ergonomic Headwear Customisation System



DIPLÔME

Inventions Geneva

SALON INTERNATIONAL DES INVENTIONS GENÈVE

Après examen, le Jury International a décidé

de remettre à: Laboratory for Artificial Intelligence in Design (AiDLab), Yan Luximon, Jie Zhang, Jun Hong See, Shun Gui

pour l'invention: Système de personnalisation des casques ergonomiques piloté par l'IA

MÉDAILLE D'OR
GOLD MEDAL
GOLDMEDAILLE

Avec les félicitations du jury
With the congratulations of the jury
Mit höchsten Empfehlungen des Preisgerichtes

Genève, le 19 avril 2024

Le Président du Jury: David Taji

Le Président du Salon: Jean-Luc Vincent

The headwear customisation system received an international technology innovation award in 2024 – the Gold Medal with the Congratulations of the Jury at the 49th International Exhibition of Inventions of Geneva.

April 2024