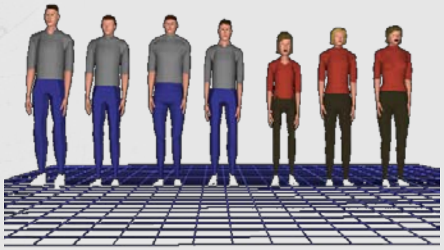
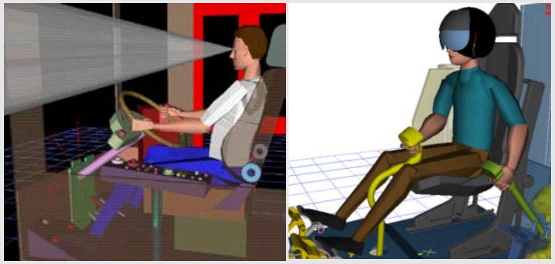
INDUSTRIAL AND MANAGEMENT
ENGINEERING, POSTECH

Ergonomic Design
Technology Lab

Development of the Boundary Zone Method for Generation of Representative Human Models





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Agenda

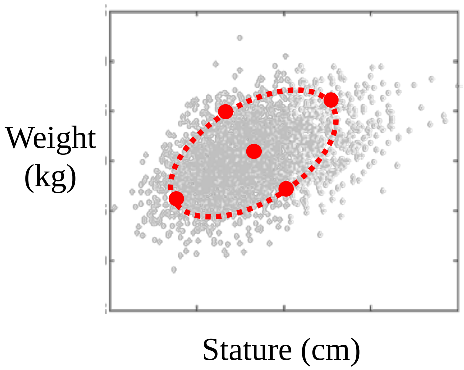
- Background: Representative Human Models
- Objectives of the Study
- Development of Boundary Zone (BZ) Method
- Comparison of BZ Method and Existing Methods
- Discussion

Representative Human Models (RHMs)

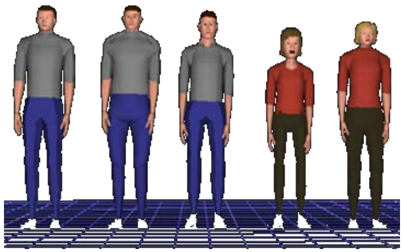
- A small group of humanoids representing a designated percentage (e.g., 90%) of the target population for product design based on anthropometric data (HFES 300, 2004)

- Benefits of RHMs in anthropometric design (HFES 300, 2004; Jung et al., 2008)
  - Efficient ergonomic design and evaluation
  - Good fit between products and the target users

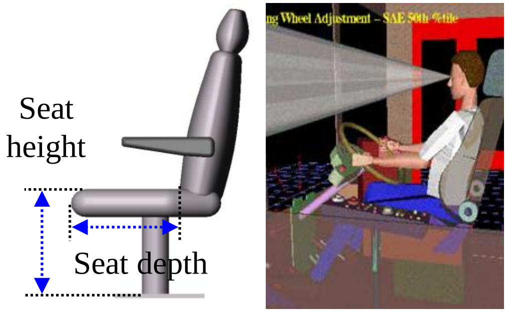
Target population



RHMs



Ergonomic design and evaluation

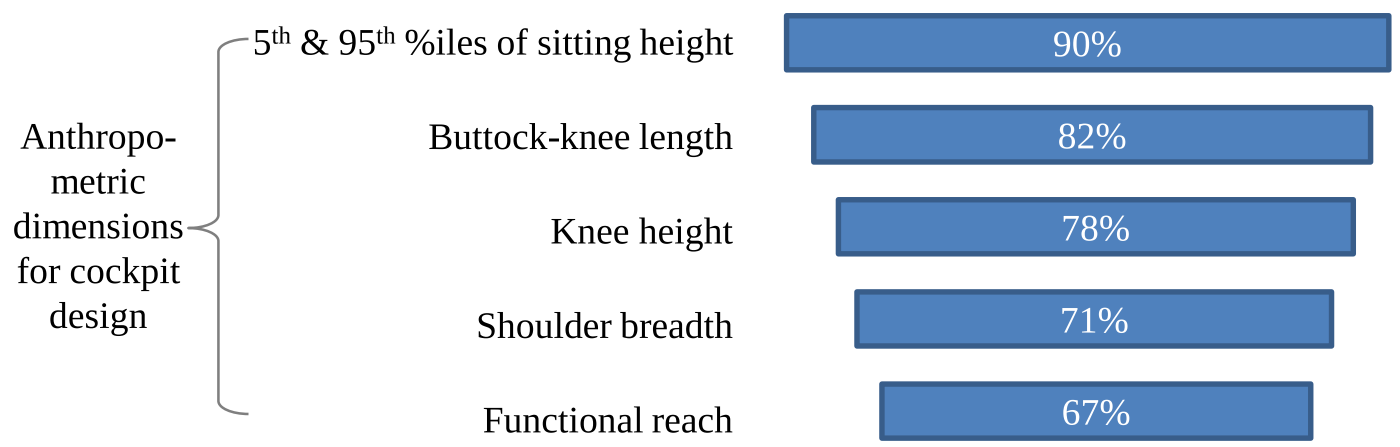


Percentile RHM-Generation Method

- Determine the sizes of RHMs as percentile values of each anthropometric dimension (HFES 300, 2004) ⇐ univariate approach

- Guarantee univariate accommodation, but not multivariate accommodation (Meindl et al., 1993; HFES 300, 2004)

Multivariate accommodation problem in the percentile method

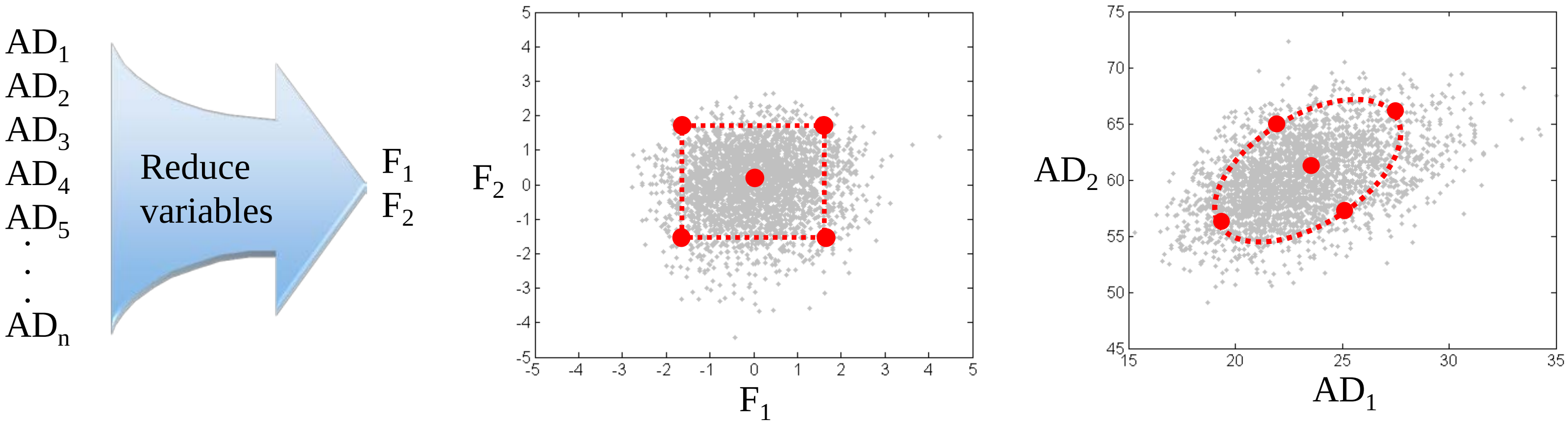


⇒ Multivariate accommodation percentage is decreasing as the number of anthropometric dimensions increases.

Multivariate RHM-Generation Methods

- Use data reduction techniques such as factor analysis and principal component analysis (Bittner et al., 1987; Kim and Whang, 1997; Meindl et al., 1993)

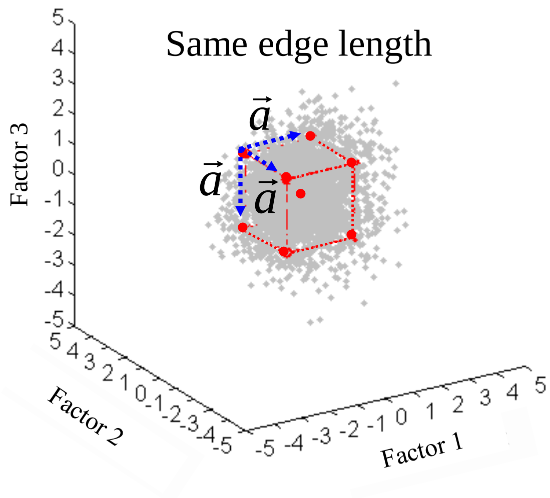
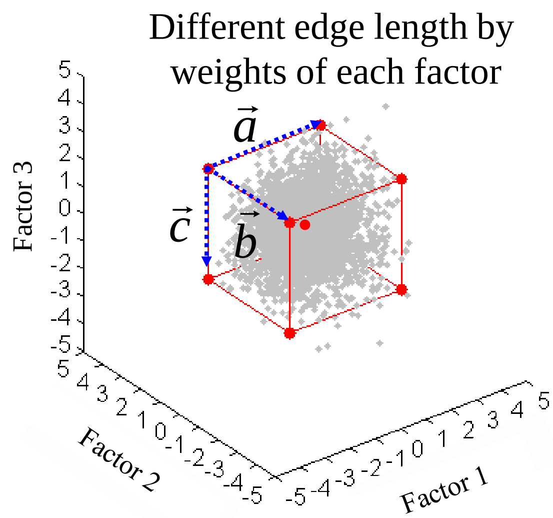
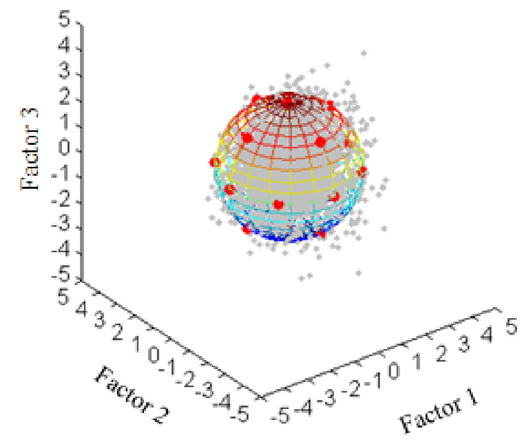
Step 1: Extract factors by data reduction techniques | **Step 2: Determine factor scores of RHMs at a boundary** | **Step 3: Convert the factor scores to body sizes of RHMs**



AD_i = anthropometric dimension i
F_j = factor j
n = number of anthropometric dimensions

Classification of Existing Multivariate Methods

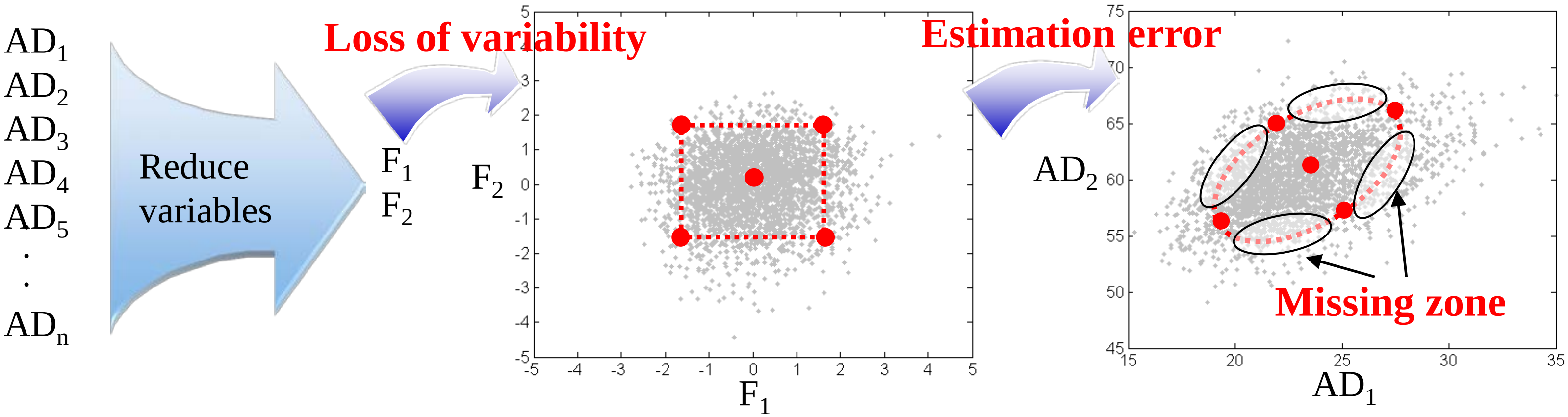
- Classified by the shape of accommodation boundary

Square (Bittner et al., 1987)	Rectangular (Kim and Whang, 1997)	Circular (Meindl et al., 1993)
		

Limitations of Existing Multivariate Methods

- Multivariate accommodation be less than the target percentage due to use of data reduction techniques (Meunier, 1998).
  - ① Loss of anthropometric variability (e.g., 20%)
  - ② Estimation error of body sizes using factor scores
  - ③ Missing zones along the accommodation boundary

Step 1: Extract factors by data reduction techniques | **Step 2: Determine factor scores of RHMs at a boundary** | **Step 3: Convert the factor scores to body sizes of RHMs**



⇒ Since these limitations decrease multivariate accommodation performance, a new multivariate RHM-generation method needs to be developed.

Objectives of the Study

① **Develop a new multivariate RHM-generation method**

- Overcoming the limitations of existing methods
  - ✓ Loss of anthropometric variability
  - ✓ Estimation error
  - ✓ Missing zone
- Statistically accommodating a designated percentage

② **Compare the new method with existing methods**

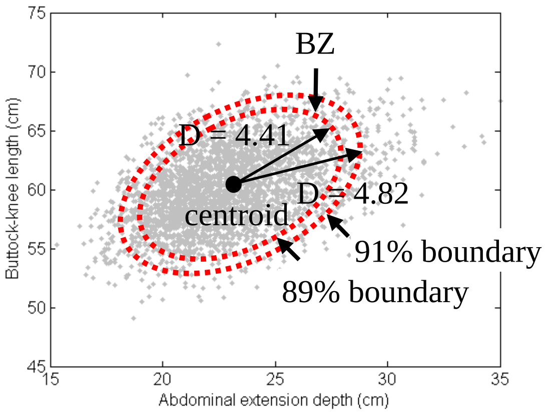
- Using the 1988 US Army data
- Considering various numbers and combinations of anthropometric dimensions

Development of Boundary Zone (BZ) Method

- Proposed a two-step RHM-generation method which generates RHMs at a BZ statistically accommodating a designated percentage of the population.

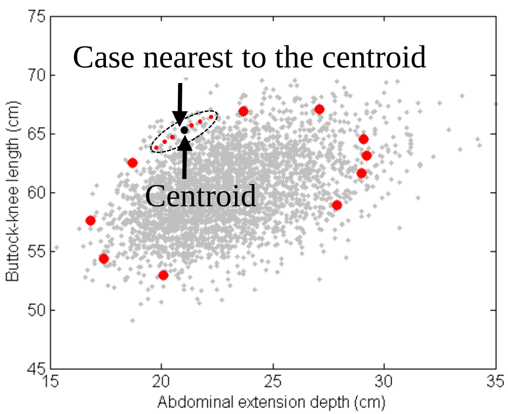
1. Formation of a BZ

- Calculating **normalized squared distances** (D) of each anthropometric case.
- Forming a **BZ** which statistically accommodates a designated percentage using D.



2. Cluster analysis for the cases within the BZ

- Clustering anthropometric cases in the BZ by the **K-means cluster algorithm**.
- Selecting a **case nearest to the centroid** of each cluster for RHM.



Step 1: Formation of a BZ

- Identify a boundary of a designated accommodation percentage using normalized squared distances (D) of each anthropometric case based normality assumption of anthropometric sizes.

$$D = (AD-\mu)^T \Sigma^{-1} (AD-\mu) \le \chi_n^2(1-p)$$

where: D = normalized squared distance

AD = values of anthropometric dimensions

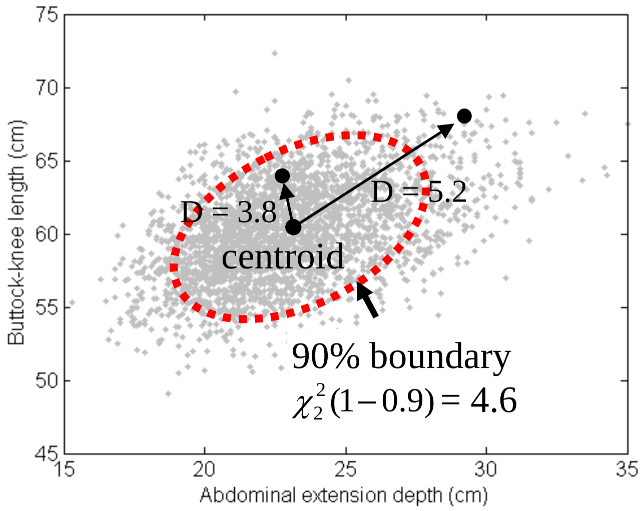
n = number of anthropometric dimensions

p = target accommodation percentage

$\chi_n^2(1-p)$ = Chi-squared value for n degree of freedom and (1-p) percent

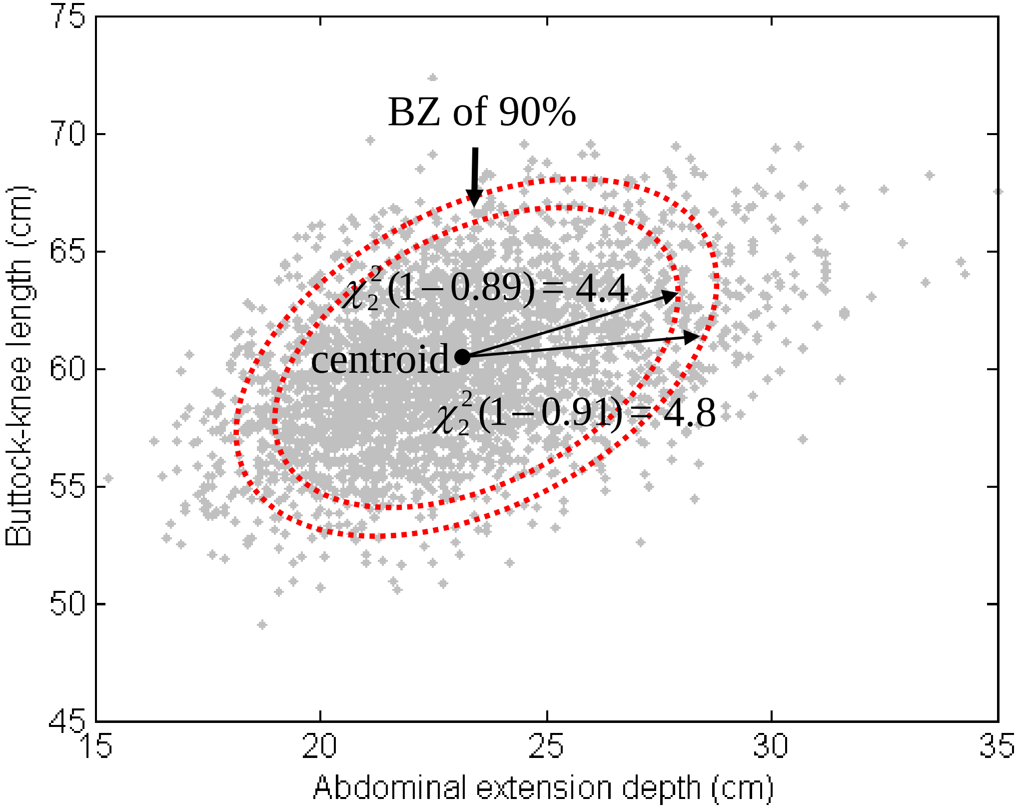
μ = averages of the values of anthropometric dimensions

Σ = variance-covariance matrix of anthropometric dimensions



Formation of a BZ (cont'd)

- Form a BZ by two boundaries that accommodates a designated percentage ± a tolerance percentage (e.g., 90% ± 1%).

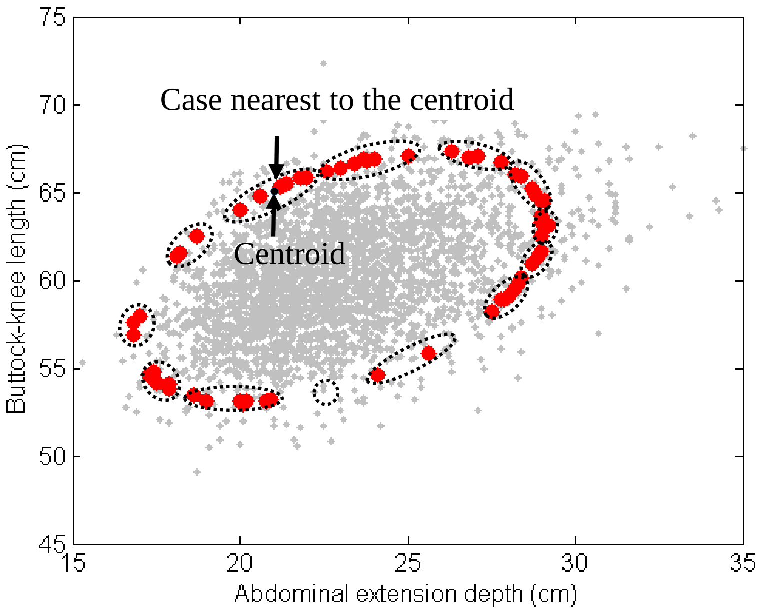


Step 2: Cluster Analysis within the BZ

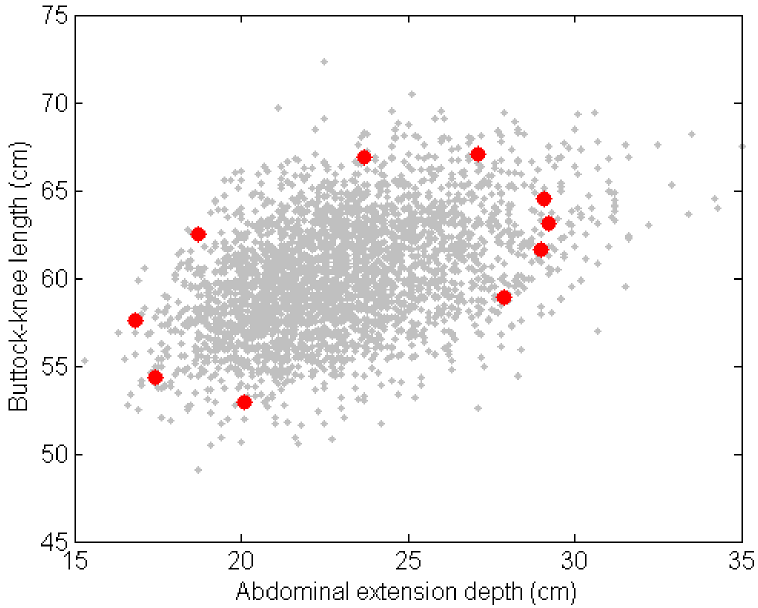
- Apply the K-means cluster analysis to the cases within the BZ due to some cases have similar body sizes.

- Select one case per cluster which is nearest to the centroid in Euclidian distance.

Cases in the BZ and clusters

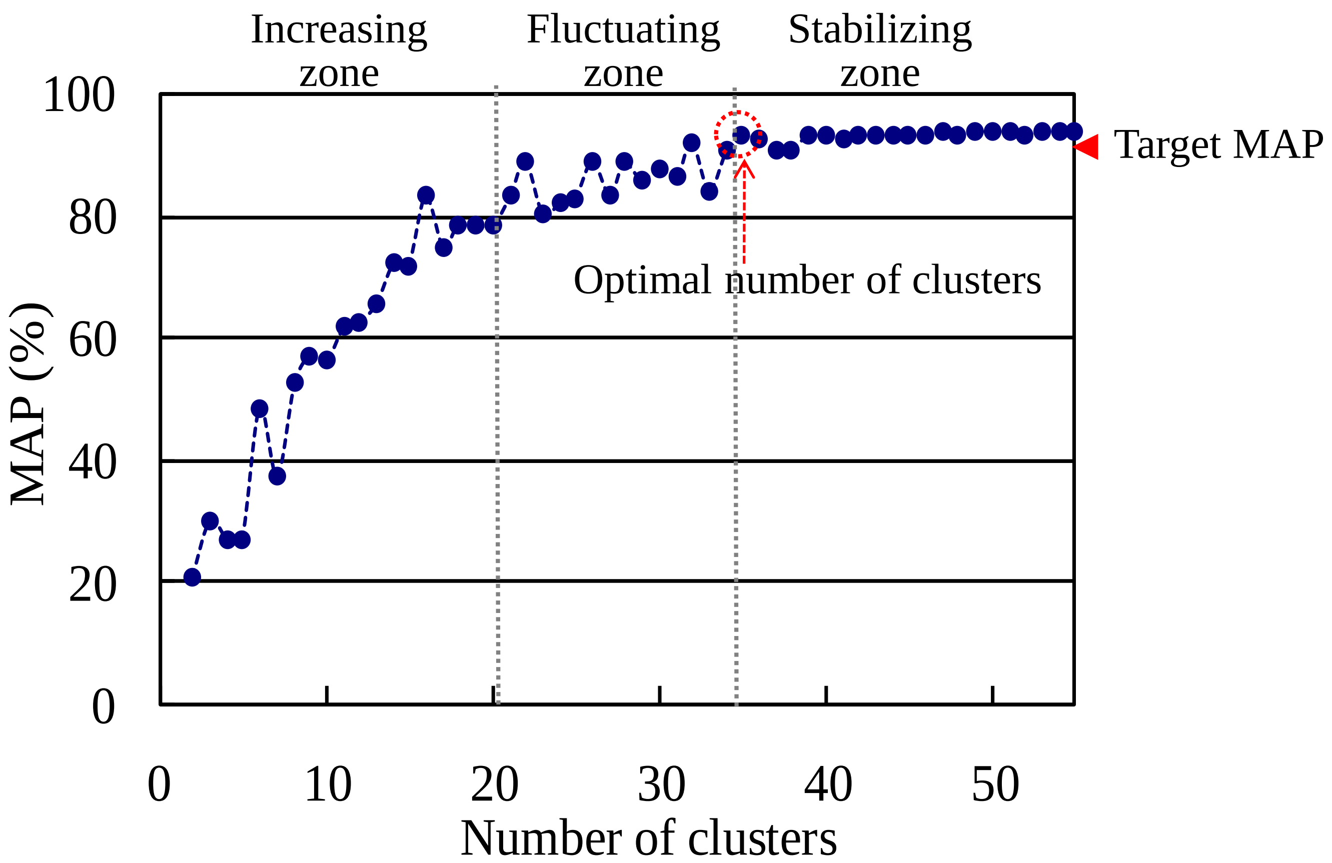


RHMs of each cluster



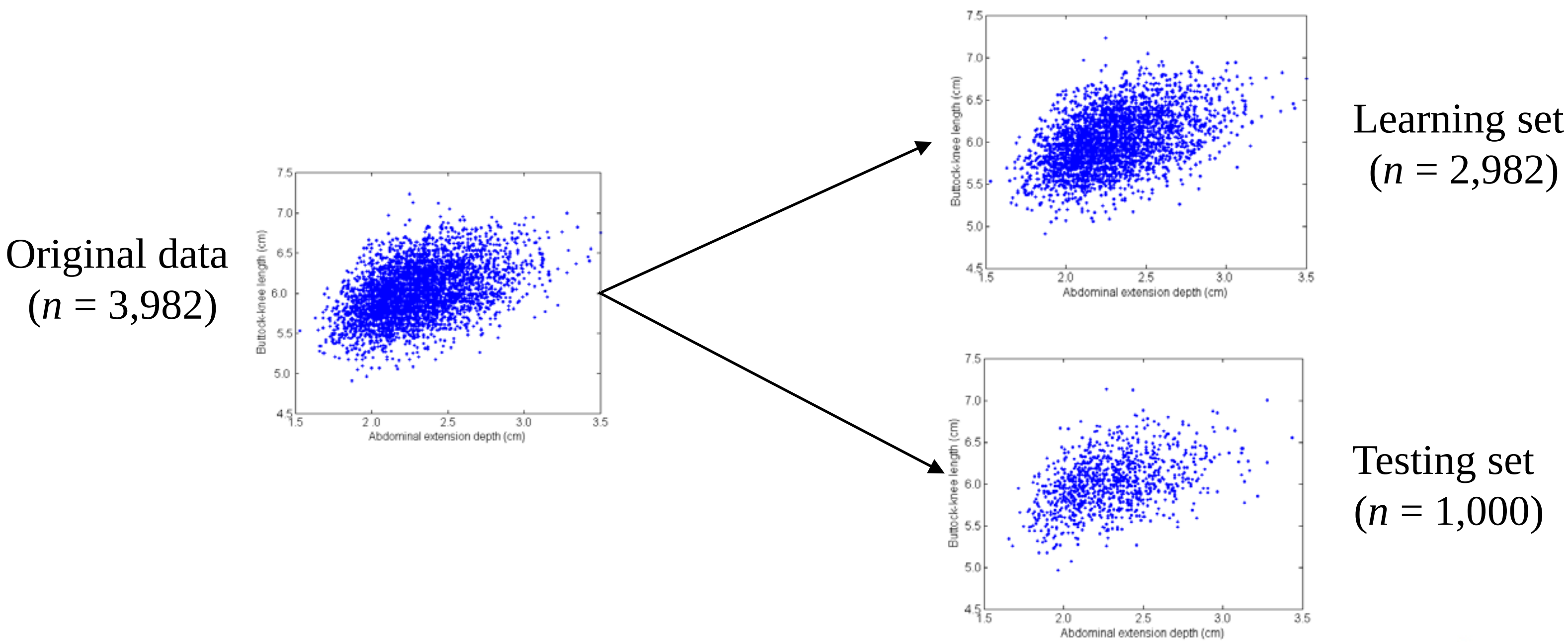
Optimal Number of Clusters

- Determine an optimal number of clusters by analyzing multivariate accommodation percentage (MAP) as the number of clusters increases.



Evaluation Method

- Anthropometric database
  - Source: The 1988 US Army data (Gordon et al., 1988)
  - Sample size (*n*): 3,987 (female = 2,213; male = 1,774)
- Random partition for cross-validation
  - Learning set (*n* = 2,982) for RHM generation
  - Testing set (*n* = 1,000) for evaluation



Anthropometric Dimension Sets

- Randomly selected anthropometric dimension sets
  - Number of anthropometric dimensions: 4 levels (n = 5, 10, 15, and 20)
  - Combination for each number level: 5

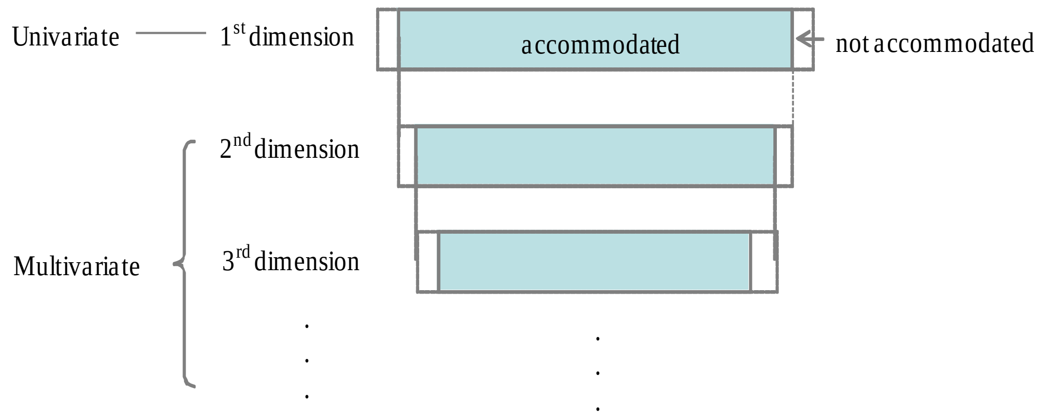
  ⇒ Sets of anthropometric dimensions were randomly selected from the 1988 US Army data.

- Design-related dimension set: ten anthropometric dimensions for computer workstation design used in ANSI/HFES (2007)

Body parts	Anthropometric dimensions	Code
Trunk	Abdominal extension depth	AD1
Arm	Elbow rest height	AD2
	Forearm-to-forearm breadth	AD3
Upper leg	Buttock-knee length	AD4
	Hip breadth	AD5
	Thigh clearance	AD6
Lower leg	Buttock-popliteal length	AD7
	Popliteal height	AD8
	Knee height	AD9
Foot	Foot length	AD10

Performance Measures

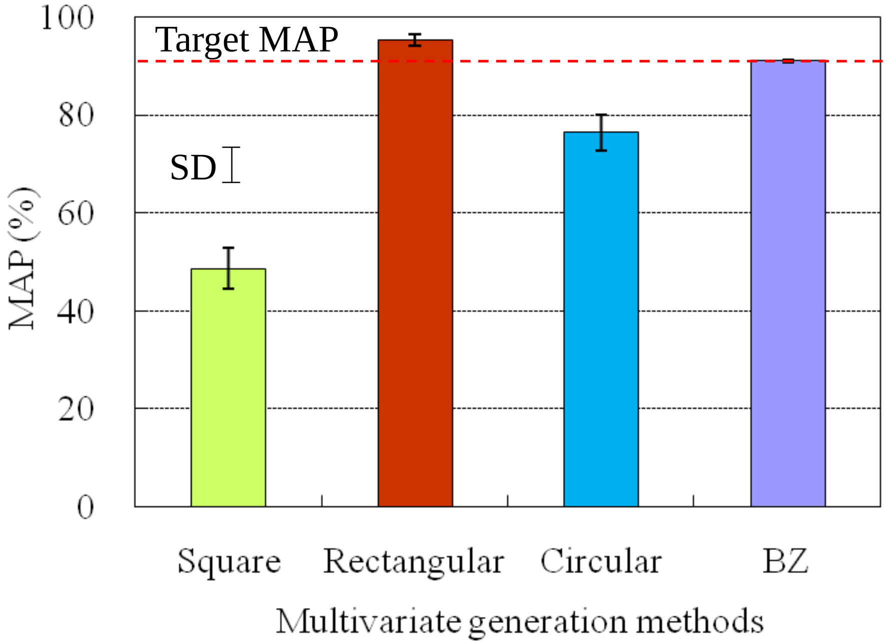
- Quantified the performances of RHM-generation methods in three aspects.

No.	Criteria	Explanation
1	Multivariate accommodation percentage (MAP)	Proportion of the target population which accommodated by the generated RHMs. Quantified by referring to previous studies (HFES 300, 2004; Hudson et al., 2006) 
2	Outlier	Whether sizes of RHMs are larger or smaller than the size ranges of the target population
3	Number of RHMs	Applicability of RHMs to ergonomic design and evaluation in a digital human simulation system

Results: MAP

- MAP of the BZ method was close to the target percentage (90%).
  - BZ method: 91% (SD = 0.6%)
  - Square method: 49% (2.5%)
  - Circular method: 76% (7.3%)

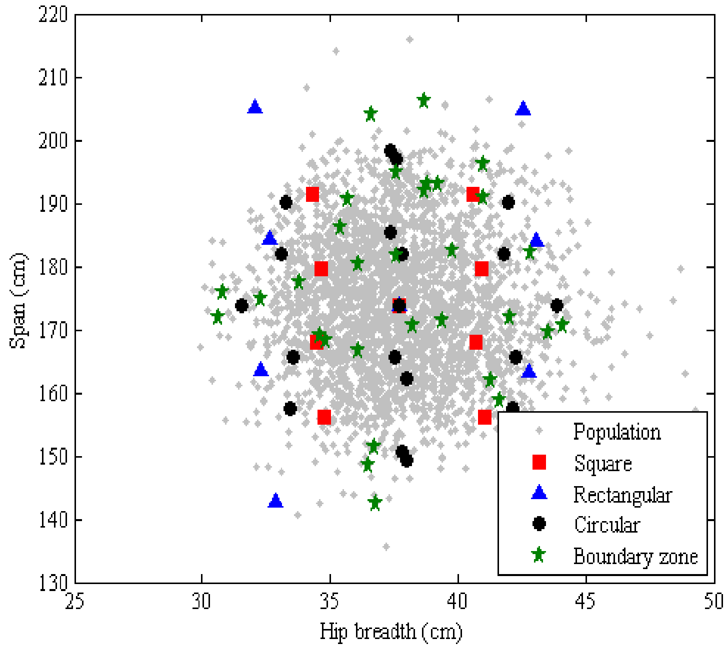
    (Square and circular methods:) < 90% ($t(20) = -23.0$, $p < 0.001$; $t(20) = -8.6$, $p < 0.001$)
  - Rectangular method: 96% (8.2%) > 90% ($t(20) = 9.8$, $p < 0.001$)



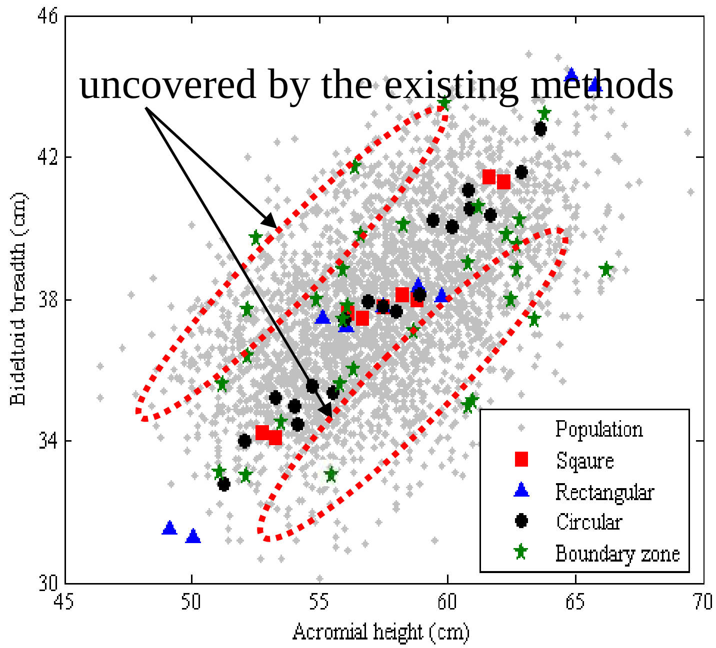
Effect of Factor Loadings on Body Size Diversity

- Lack of body size diversity for pairs of anthropometric dimensions having similar factor loadings in the existing methods.

Different factor loading dimensions

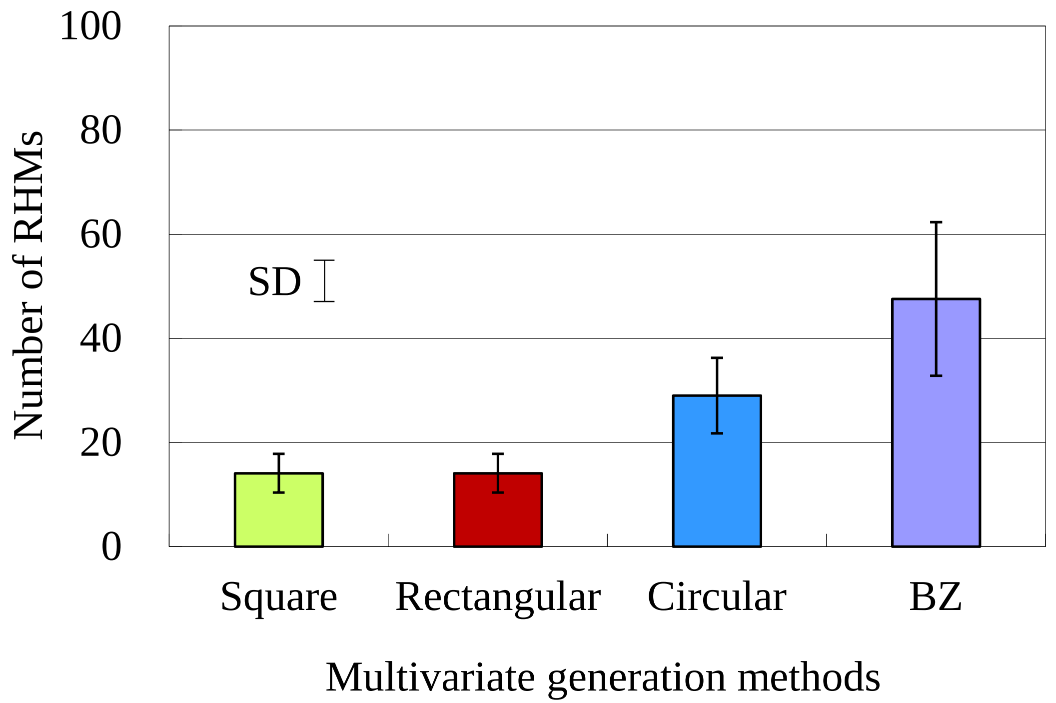


Similar factor loading dimensions



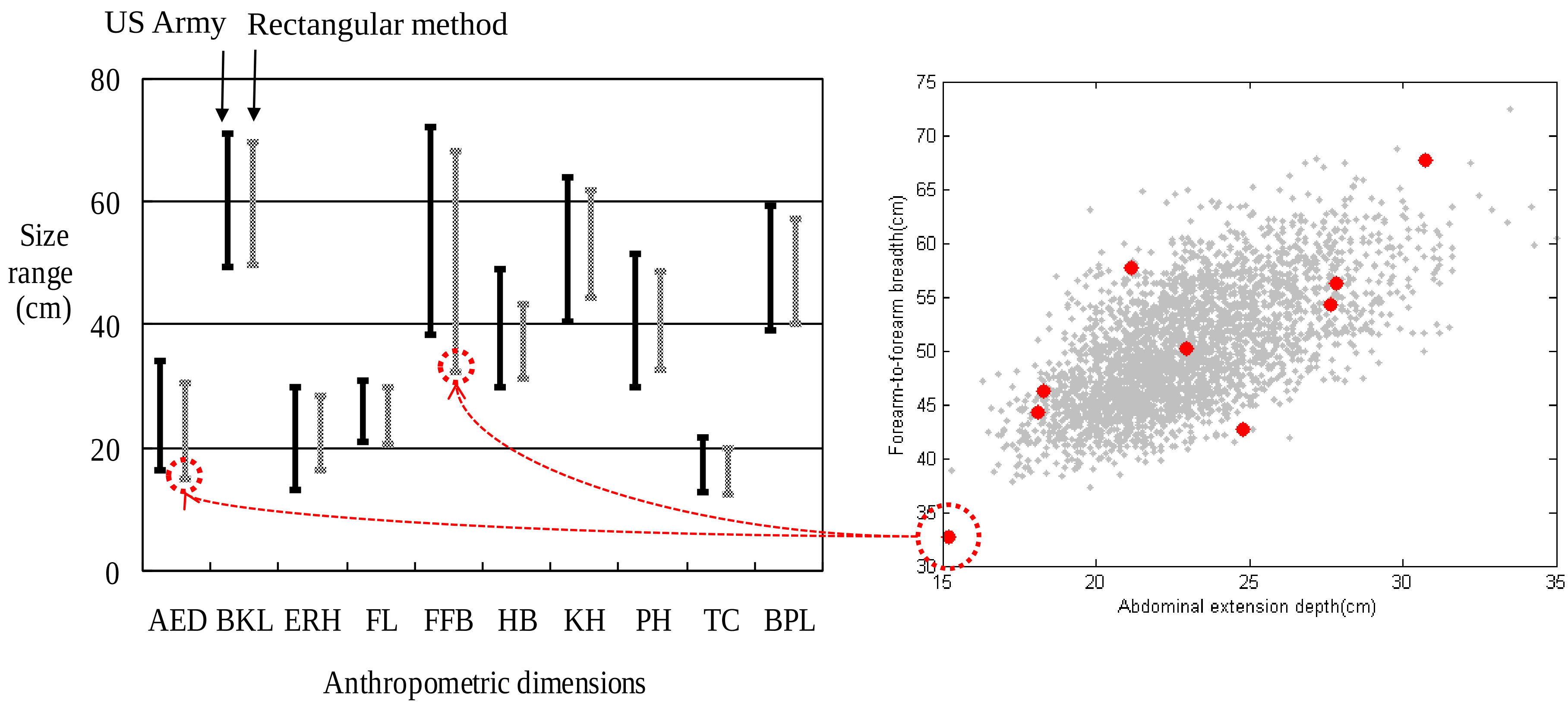
Number of RHMs

- Numbers of RHMs for the BZ method was significantly larger.
  - BZ method: 48 (SD = 29)
  - Square and rectangular methods: 14 (8) (t (22) = -5, $p < 0.001$)
  - Circular method: 29 (14) (t (22) = -2.6, $p = 0.02$)



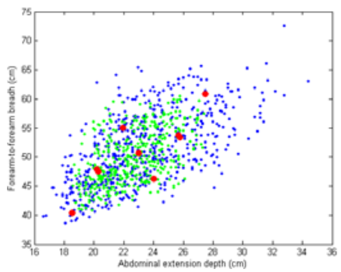
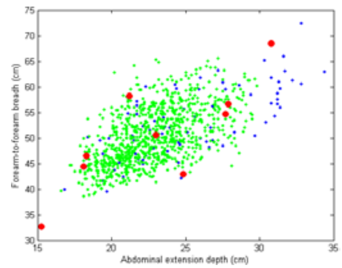
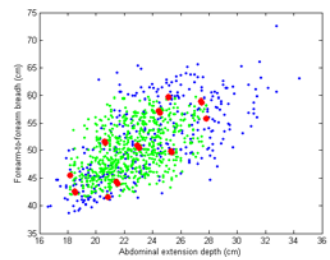
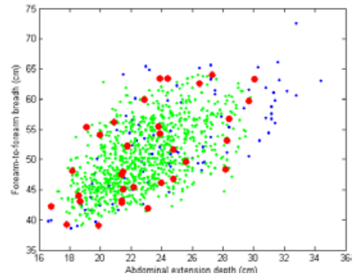
Outliers in the Rectangular Method

- Generated RHMs out of the size ranges of the target population.



Summary

- ❑ The BZ method is superior to the existing methods in representativeness.

Classification	Square method	Rectangular method	Circular method	BZ method
Bivariate plot*				
# RHMs (SD)	14 (8) ☺	14 (8) ☺	29 (14) 😐	48 (29) ☹
MAP (SD)	49% (2.5%) ☹	96% (8.2%) 😐	76% (7.3%) ☹	91% (0.6%) ☺
Outlier	No ☺	Yes ☹	No ☺	No ☺
Size diversity**	No ☹	No ☹	No ☹	Yes ☺

* Red dot: RHM, blue dot = not accommodated, green dot = accommodated

** Size diversity for pairs of anthropometric dimensions

Discussion

- Developed an effective RHM-generation method
  - Formation of a BZ using normalized squared distance
  - K-mean cluster analysis for cases within the BZ
  - Selection of one case nearest to the centroid of each cluster for RHM
- Compared the BZ method with the existing methods
  - Proposed performance metrics for evaluation of RHM-generation methods
  - Comprehensive evaluation for various conditions of anthropometric dimensions (n = 5, 10, 15, and 20)

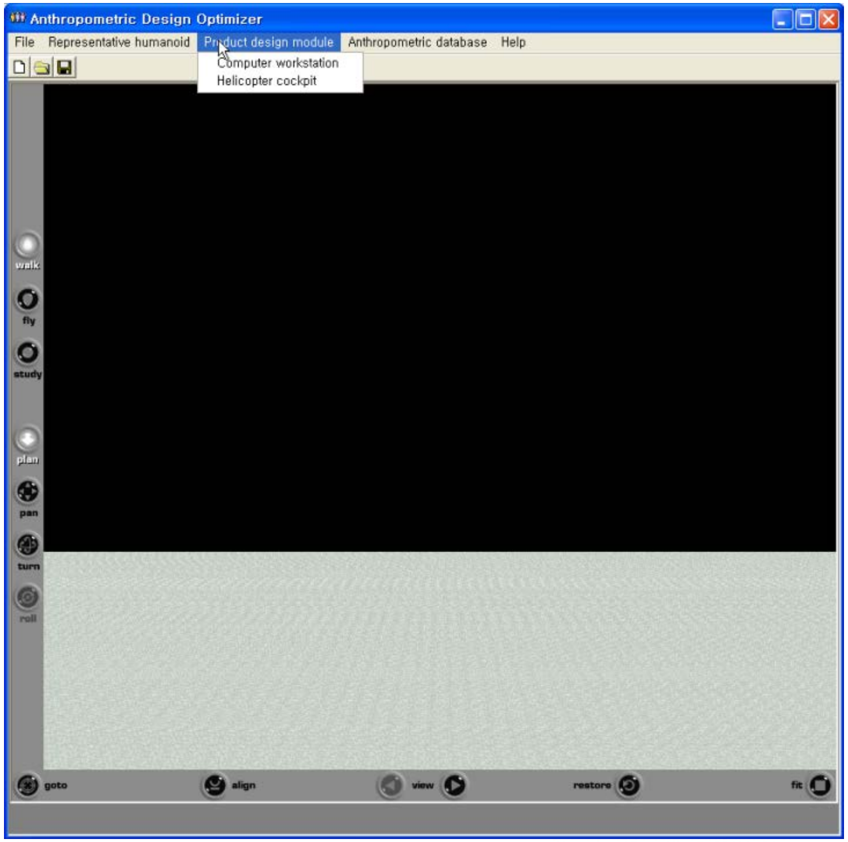
  ⇒ Evaluation results can be used for understanding the performance characteristics of multivariate RHM-generation methods.
- Identified the limited applications of the existing methods
  - Under- or over-fitting than a designated accommodation percentage
  - Careful use of the existing methods if highly correlated anthropometric dimensions are considered

Limitation of the BZ Method

- Limited application of the BZ method to digital human modeling systems due to large number of RHMs
  - Creating humanoids by inputting their sizes
  - Positioning the humanoids
  - Manipulating postures of the humanoids

  } Time and efforts ⇑ as # of RHMs ⇑

⇒ An ergonomic design supporting system has been in development which can analyze an optimal design based on functional relationships between anthropometric dimensions and design variables



Q & A

Thank you for your attention…