A Multivariate Evaluation Method for Representative Human Model Generation Methods: Application to Grid Method

Ergonomic Design Technology Lab

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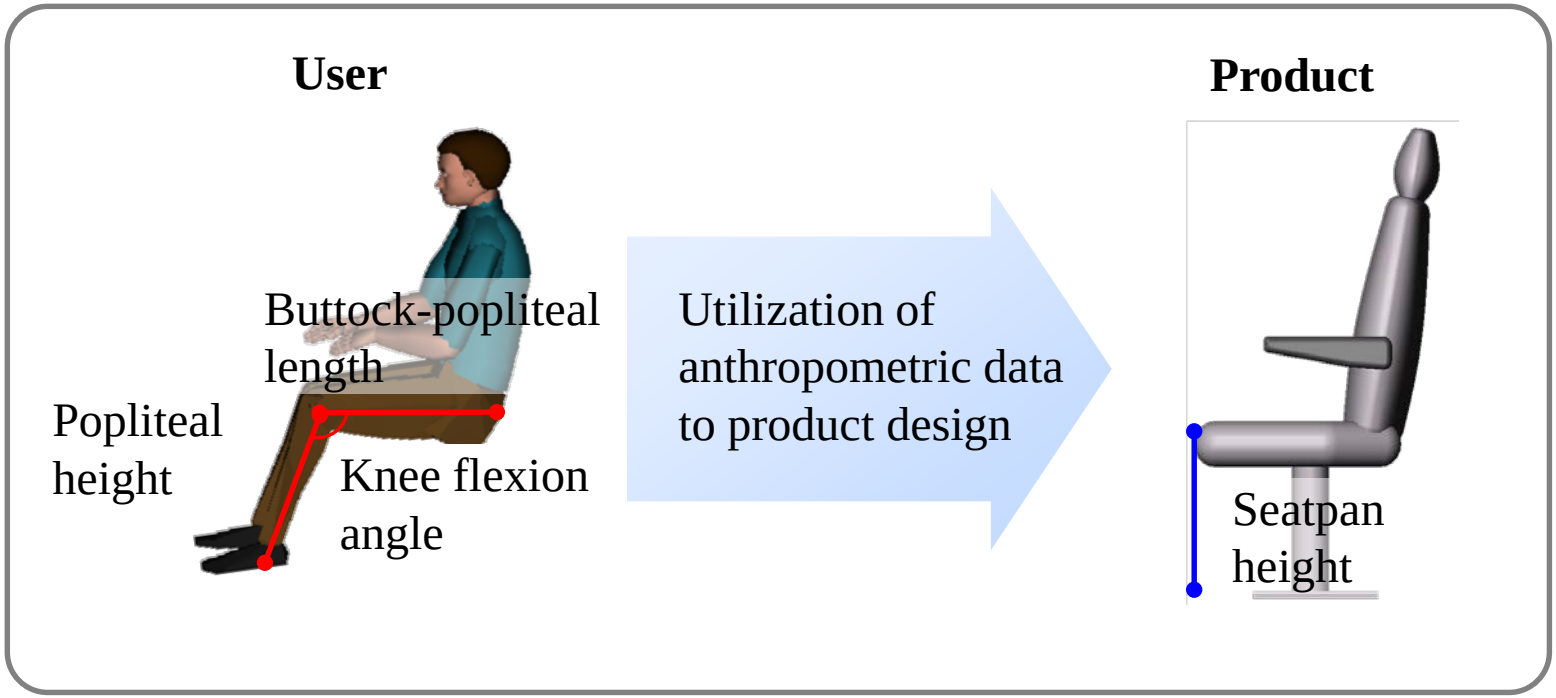
Agenda

- Background
- Objectives of the Study
- Evaluation Method
- Results
- Discussion

Anthropometric Product Design and Evaluation

- To optimize human performance by achieving the best possible fit between products and the users (HFES 300, 2004)

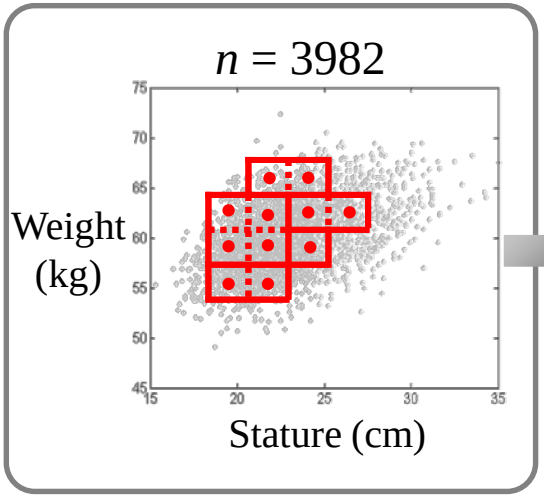


⇒ To achieve good fit of products to the users, representative human models (RHMs) appropriately representing the body sizes of the target population are important

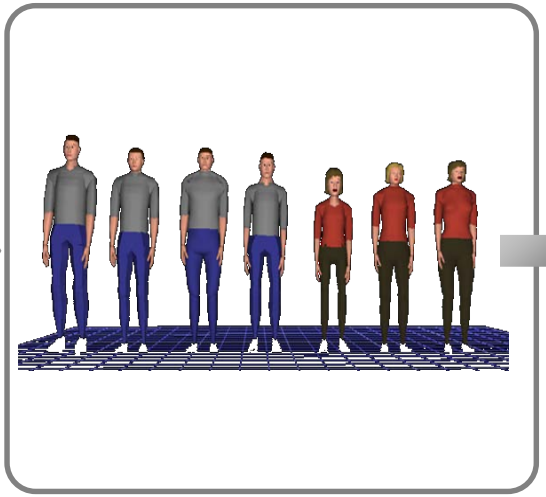
Representative Human Models (RHMs)

- A small number of humans (3 to 20) which are statistically representing a designated percentage (e.g., 95%) of the target population
  - Good fit between products and the users
  - Efficient ergonomic design and evaluation

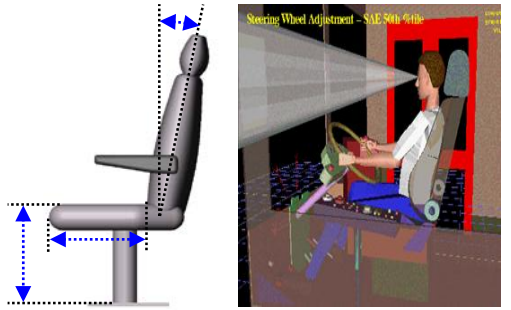
Target population



A group of RHMs

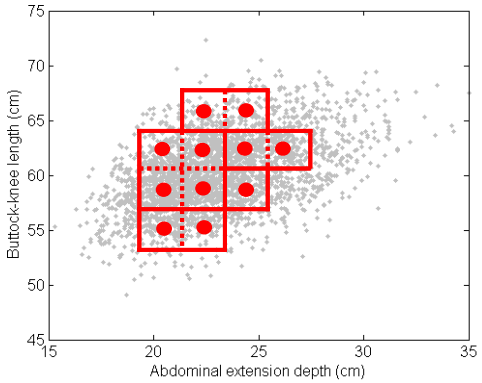
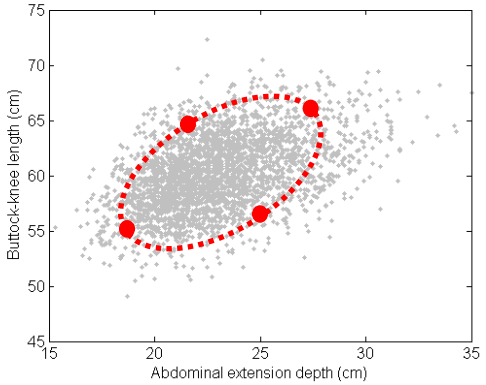


Anthropometric design & evaluation



Taxonomy of RHMs Generation Methods

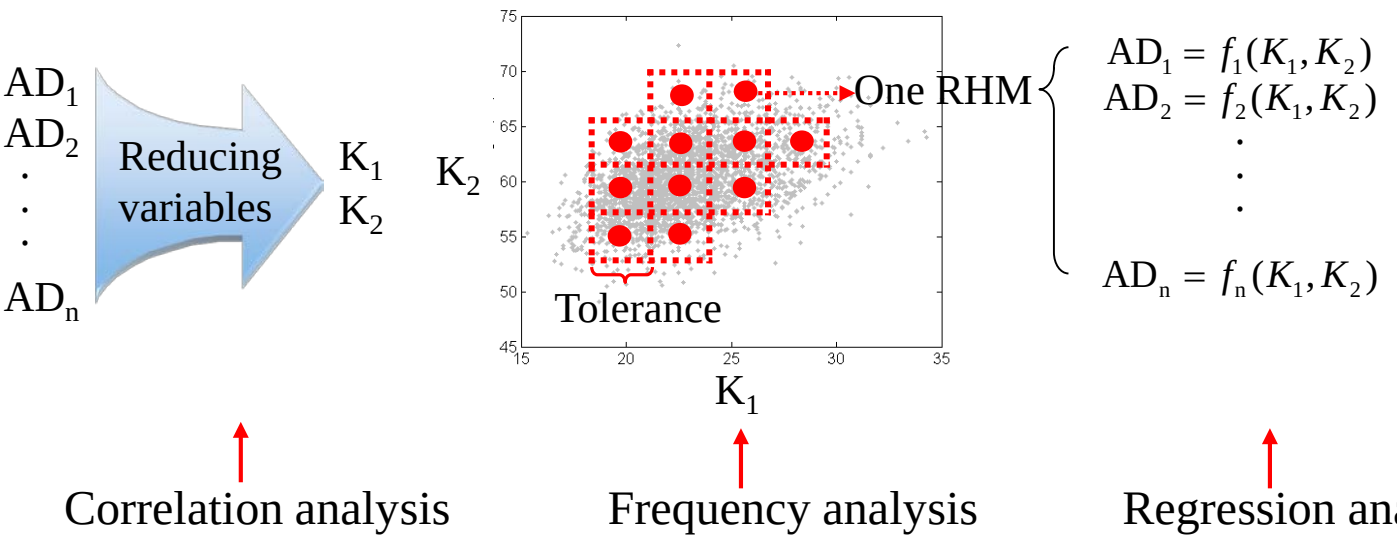
- Depending on the characteristic of a product of interest, RHMs can be generated at the scattered grids or the boundary

Classification	Distributed method	Boundary method
Illustration		
Application	Multiple-size product design (e.g., garment)	One-size product design (e.g., cockpit)
Methods	• Grid method (Robinette and Annis, 1986) • Cluster method (Laing et al., 1999) • Optimization (McCulloch et al. 1998)	• Square method (Bittner, 2000) • Circular method (Meindl et al. 1993) • Rectangular method (Kim and Whang, 1997)

State-of-the-Art: Distributed Methods

- 3-step RHMs generation process of distributed methods

Step 1: Selection of key dimensions	Step 2: Formation of grids	Step 3: Generation of RHMs



Note: AD = anthropometric dimension, K = key dimension, RHM = representative human model

⇒ Since the distributed methods mainly consider key dimensions in the generation of RHMs, other dimensions which are still important to design are ignored.

Objectives of the Study

1. Development of a multivariate performance evaluation process for distributed RHM generation methods

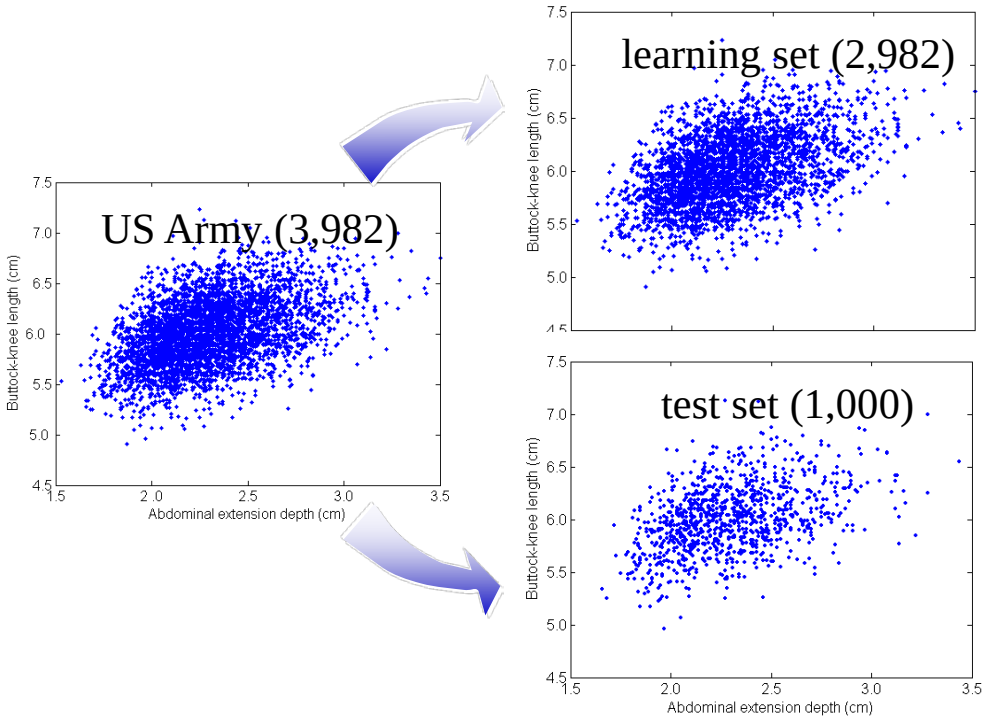
2. Application of the multivariate evaluation process to the grid method

3. Investigation of factors affecting the multivariate performance of the grid method

Method: Anthropometric Dimensions and Data

- To evaluate the performance of the distributed method, 10 anthropometric dimensions related to computer workstation design (ANSI/HFES, 2007) were used
- US Army anthropometric data (Gordon, 1988)
  - *n* = 3,987 (female = 2,213, male = 1,774)
  - Randomly divided into learning (2,982) and testing (1,000) sets

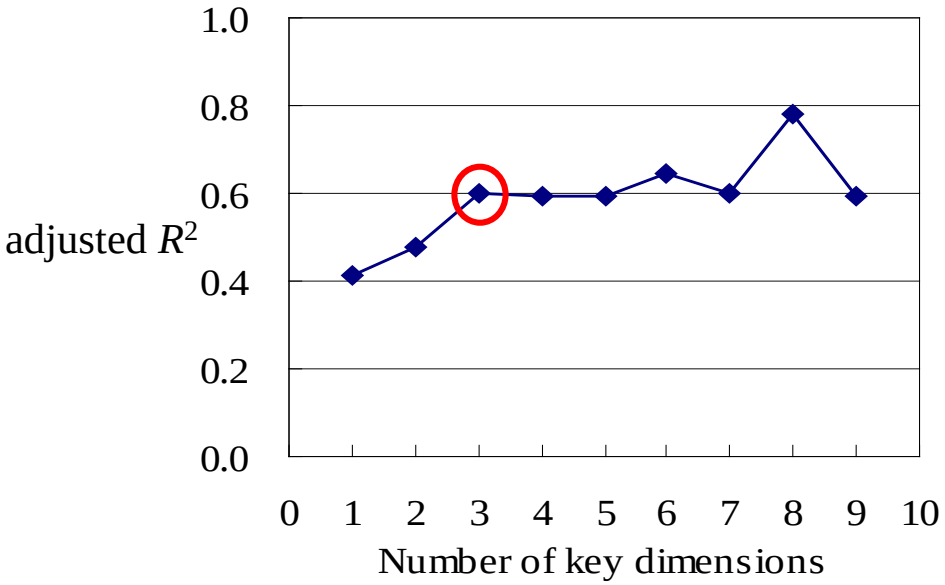
Anthropometric dimensions
1. Abdominal extension depth
2. Buttock-knee length
3. Buttock-popliteal length
4. Elbow rest height
5. Foot length
6. Forearm-to-forearm breadth
7. Hip breadth
8. Knee height
9. Popliteal height
10. Thigh clearance



Key Dimension Selection

- Selection criteria of key dimensions (Hidson, 1991)
  - Statistical relationship between key dimensions and other dimensions
  - Small number of key dimensions (e.g., 1 to 5)

- To identify an optimal set of key dimensions, the trend of maximum average of adjusted R^2 was analyzed for different numbers and combinations of key dimensions

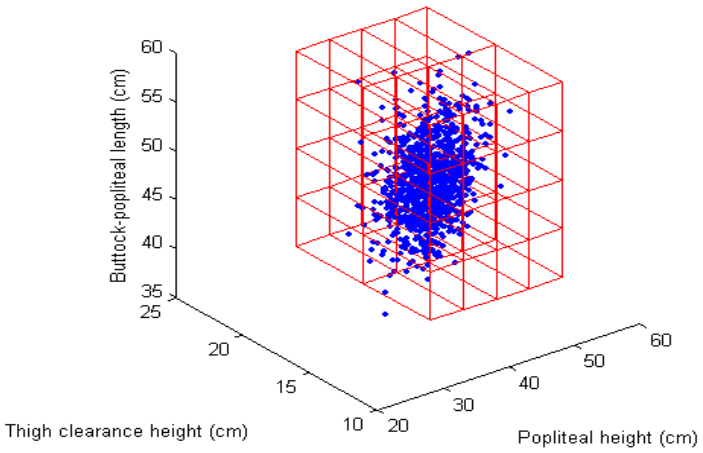


Key dimensions selected
- Popliteal height
- Thigh clearance
- Buttock-popliteal length

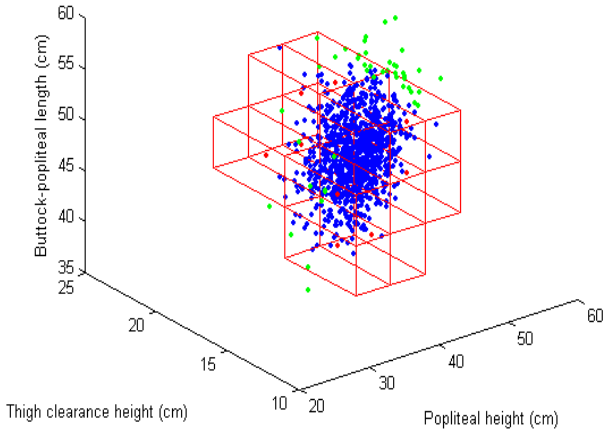
RHMs Generation by the Grid Method

- In the space formed by the key dimensions, grids covering the target population were generated by applying a tolerance value of ±2.5 cm, which was determined by referring to previous studies (Moon, 2002; ANSI/HFES, 2007)
- Of the generated grids, 12 grids showing a relatively large coverage rate were selected to accommodate the 95% of the target population

Grids covering the target population



Representative grids accommodating 95%



RHM Body Size Estimation

- Estimation of the body sizes of the 12 RHMs
  - Key dimensions: the centroid values of the grids
  - Other dimensions: estimated by regression equations with key dimensions as regressor developed by stepwise regression analysis

Dimension	Code	Regression equation	Adjusted R^2
Hip breadth	AD3	18.87 + 0.60×AD2 - 0.59×AD1 + 0.85×AD5	0.42
Elbow rest height	AD4	25.88 - 0.43×AD2 + 0.19×AD1 + 0.59×AD5	0.11
Buttock-knee length	AD6	2.52 + 0.95×AD2 + 0.10×AD1 + 0.43×AD5	0.96
Abdominal extension depth	AD7	-3.53 + 0.24×AD2 - 0.15×AD1 + 1.27×AD5	0.43
Forearm-to-forearm breadth	AD8	-3.86 - 0.36×AD2 + 0.76×AD1 + 2.48×AD5	0.55
Foot length	AD9	3.40 + 0.41×AD1 + 0.32×AD5	0.81
Knee height	AD10	3.11 + 0.19×AD2 + 0.83×AD1 + 0.44×AD5	0.96

RHM Body Size Estimation: Results

- The body sizes of the 12 RHMs which accommodate the 95% of the target population

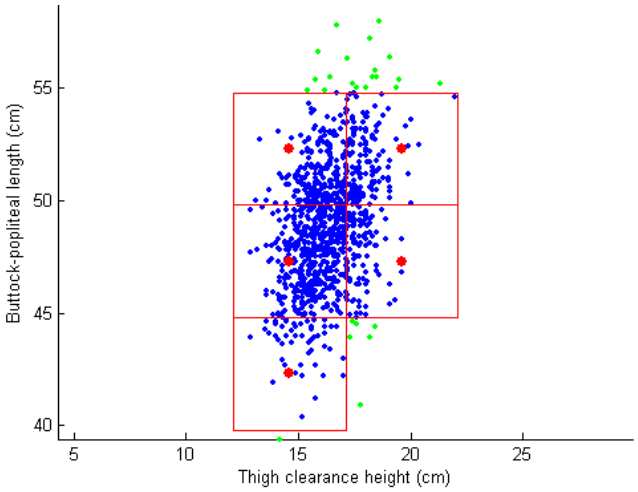
unit: cm

RHM No.	Key dimensions			Other dimensions						
	Popliteal height	Buttock-popliteal length	Thigh clearance	Abdominal extension depth	Buttock-knee length	Elbow rest height	Foot length	Forearm-to-forearm breadth	Hip breadth	Knee height
1	35	15	42	20	52	23	23	44	36	46
2	35	15	47	21	57	21	23	42	39	47
3	35	20	47	28	59	24	24	54	43	50
4	40	15	42	19	53	24	25	48	33	51
5	40	15	47	21	58	22	25	46	36	52
6	40	15	52	22	62	20	25	44	39	52
7	40	20	47	27	60	25	26	58	40	54
8	40	20	52	28	65	23	26	56	43	55
9	45	15	47	20	58	23	27	50	33	56
10	45	15	52	21	63	21	27	48	36	57
11	45	20	47	26	60	26	28	62	37	58
12	45	20	52	27	65	24	28	60	40	59

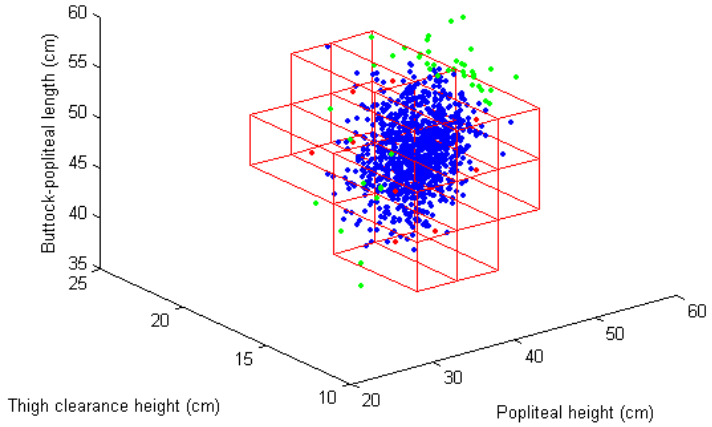
Quantification of Multivariate Accommodation Percentage

- Accommodation percentage: the proportion of cases which belong to the grids formed along the generated RHMs by applying a tolerance value of ± 2.5 cm (McCulloch et al., 1998)
- The accommodation percentage can be calculated for different numbers (1 to 10) of anthropometric dimensions

Bivariate accommodation percentage



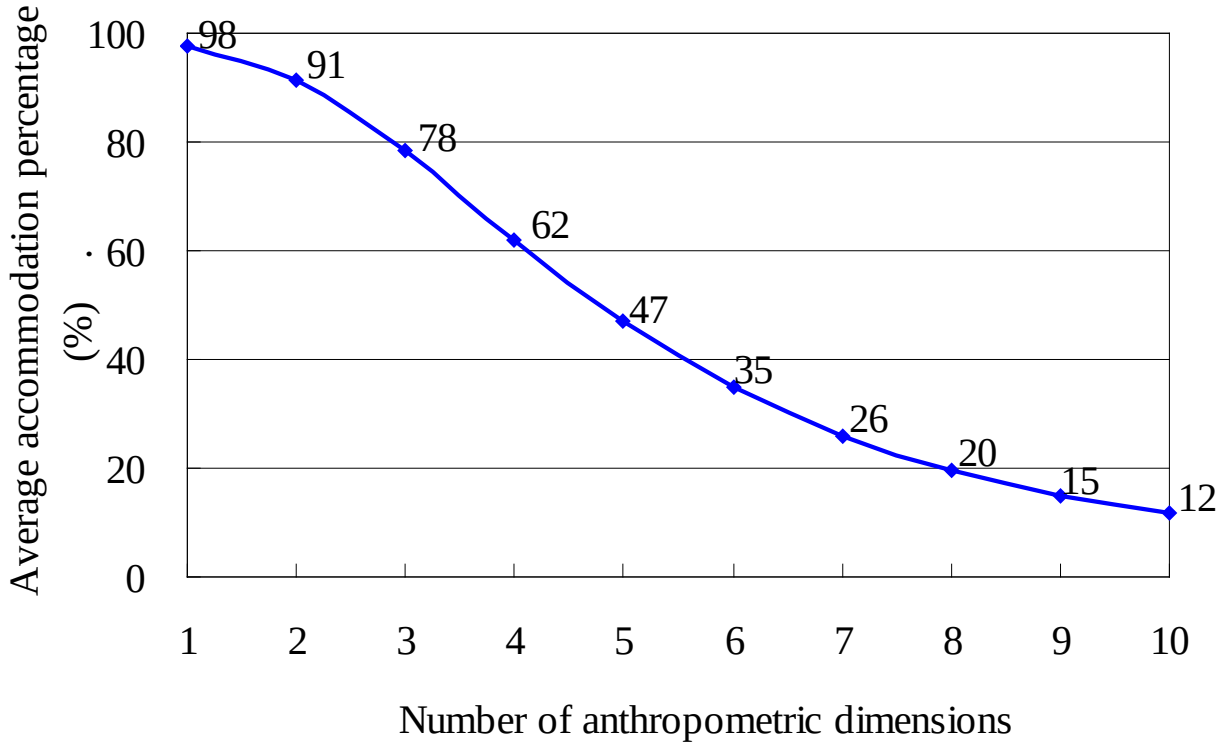
Multivariate accommodation percentage



Note: blue dot = accommodated people, green dot = not accommodated people

Results: Multivariate Accommodation Percentage

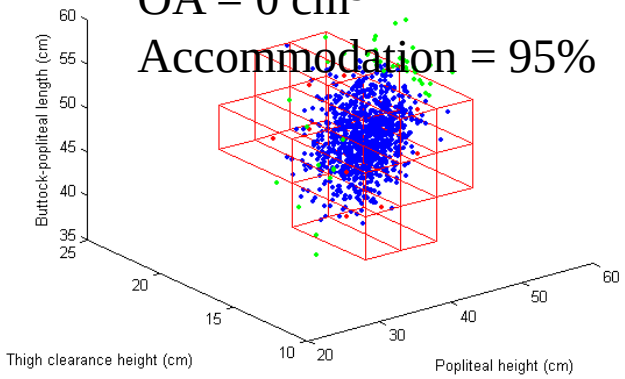
- The accommodation percentages of the generated RHMs decreased as the number of anthropometric dimensions increased.
- This decreasing trend was caused due to estimation inaccuracies of anthropometric dimensions by the key dimensions.



Three Factors Affecting Performance

1. Overlap area of grids (OA)

OA = 0 cm^3
Accommodation = 95%



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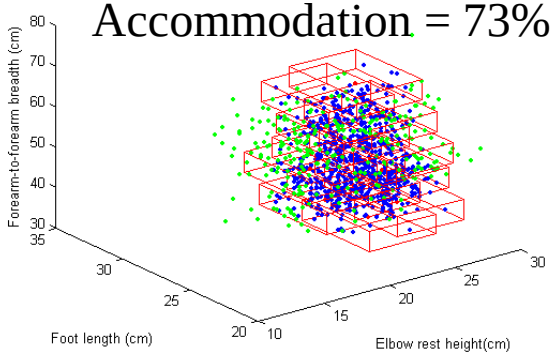
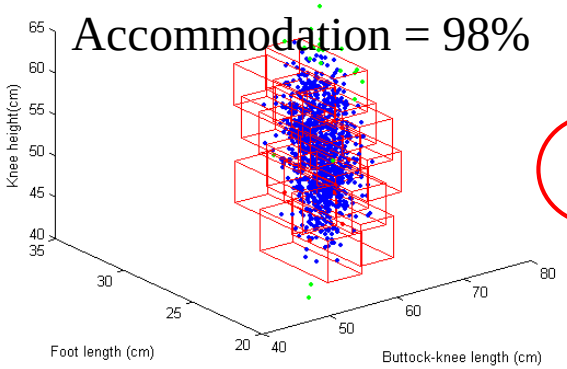
OA = 547 cm^3
Accommodation = 73%



2. Average adjusted R^2 (AR) between key dimensions and other dimensions

AR = 89%
Accommodation = 98%



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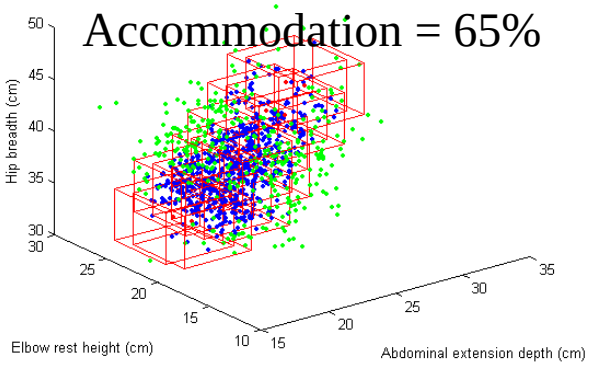
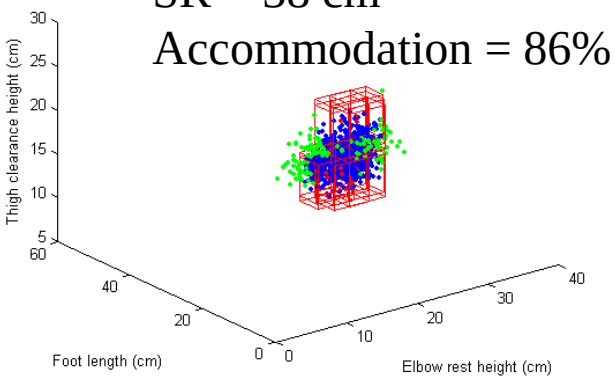
AR = 32%
Accommodation = 65%



Three Factors Affecting Performance

3. Sum of the ranges (SR) of anthropometric dimensions

SR = 38 cm
Accommodation = 86%



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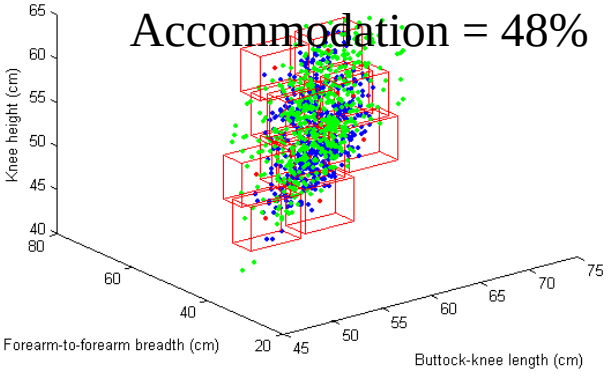
SR = 82 cm
Accommodation = 48%



Statistical Significance and Influence of the Factors

- Statistical significance of the three factors and their relative influence on accommodation performance were examined by multiple stepwise regression analysis

  1) Standardization of the three factors (0 to 1) to investigate their relative influence on the performance

  2) Stepwise regression to build the best regression model (p_{in} = 0.05 and p_{out} = 0.1)

  3) Adjusted R^2 of the regression model = 0.85

$$\text{Accommodation \%} = 56.5 + 55.2 \times \text{AR} - 39.8 \times \text{OA} - 20.1 \times \text{SR}$$

where: AR = average adjusted R^2,
OA = overlap area of grids,
SR = sum of body size ranges

- Relative influence order: AR (2.7 times) > OA (2.0 times) > SR (baseline)

Discussion

- Quantitative evaluation of the grid method: Accommodation percentage dramatically ⇓, the number of anthropometric dimensions ⇑ (98% for 1 dimension, 12% for 10 dimensions)

- Investigation of factors affecting the performance of the grid method
  - 3 factors (AR, OA, and SR) influencing on the performance
  - A better RHM generation method can be developed by considering the characteristics of the 3 factors

- The multivariate evaluation process in this study can be used to evaluate:
  - Other existing distributed and boundary RHM generation methods
  - A new RHM generation method

Q & A

Follow-Up Study