THREE DIMENSIONAL CRANIOFACIAL ANTHROPOMETRY

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Abstract

The object of this study is to build a 3D craniofacial database, from which typical craniofacial manikins were selected to be used in the design and standardization of individual protection devices, such as respiratory masks, safety helmets and safety goggles. A 2.5D photo-grating measurement system consisted of 6 LCD grating projectors and 4 CCD cameras was used to measure approximately 100,000 points of craniofacial surface. The measurement takes about 94 seconds, and the precision level is about 0.5mm. 1073 randomly selected workers from Taiwanese workers population were measured. From this database, 2 sizes of typical craniofacials were selected to be used for the design of helmet, and 3 for the design of respiratory masks and safety goggles. The select of typical craniofaces for helmet is to choose the one which covers 97.5 percentile of both head width and head depth as the upper limit for the large size, and the one which covers 2.5 percentile of that as the lower limit for the small size. The selection of large, middle and small sizes is to compare the differences of 29 cutting plane contours of one single individual with the rest of the same size group, and to choose the one who had least difference as the typical craniofacial in the group. These five typical craniofacials were all carved into 3D models using CNC machines. These models are to be used for the design and for standardization of safety helmets, respiratory masks and safety goggles.

Introduction

The objective of this study is to build a 3D craniofacial database, from which, typical craniofacial manikins were selected to be used for the design and standardization of individual protective device, such as respiratory masks, safety helmets and goggles. Nowadays, in Taiwan's highly industrialized society, workers, engineers as well as labor inspectors must work in the environments which are full of toxic gases, aerosols, dusts and falling objects. Because hazardous sources can not always be controlled and limited effectively, their skulls, faces, eyes and respiratory tracts will be severely threatened. Under these circumstance, individual protective devices, such as safety helmets, safety goggles and respiratory masks will be the last means to protect their safety and health. In order to design suitable individual protective devices for these people, it is necessary that we have a 3D craniofacial database for the target users - Taiwanese labor's population.

The amount of people who must wear protective devices is massive and the occupational injuries and disorders due to unsuitable protective devices are even astonishing. For respiratory masks, according to the report of Council of Labor's Affair's study [1], the proportion of workers who need to wear protective device is 24.42%, among them 60.13% need to wear respiratory masks. And according to the data of Labor's Insurance Compensation between 1985 and 1993 [2], among a total of 853 cases, 80% is pneumoconiosis. For safety helmets, unsuitable safety helmets have caused a astonishing injuries and fatalities. According to 1993 Labors Inspection Annual Report [3], there were 247 head injuries and fatal accidents which were struck by falling objects, and the total loss is unevaluated. For safety goggles, according to 1993 Labor's Insurance Statistics in Taiwan Area [4], there were 117 cases of visual disability due to eye injuries, this figure was actually far under estimated because of unreasonable lower insurance coverage for occupational causes.

Among the reasons for the aforementioned injuries and fatalities, unsuitable design of protective devices is un-neglectable. For all craniofacial related protective devices, especially respiratory masks. the basic design requirement is that it must fit tightly to the skull and face. To tailor an individualized respiratory mask which will fit tightly for a specific individual is not an easy task, moreover, our skulls and faces are various in sizes and different in shapes. It is far more difficult to fit a large face of individual with only a very limit sizes of masks. what even worse is that most masks sold in Taiwan's market are imported, these masks were designed for foreigners. It is obvious that foreigners' skulls and faces are quite difference from ours, therefore, these masks are undoubfully unsuitable for our skulls and faces. As a consequence, unsuitable protective devices will not only lower its protection effectiveness, but also cause discomfort to the users and lower their willingness to wear.

In order to design suitable individual protective devices. We must build our own craniofacial database for the use of design and standardization of these devices. Now, most craniofacial databases in the world [5],[20] are only the collections of basic 2D measurements, such as face length, face width, head depth and mouth width etc.. These 2D measurements are far from appropriate to be used for the design of skull and face related protective devices, especially respiratory masks. The lack of complete detail 3D craniofacial data is the major cause that the design quality of protective devices can not be improved. In order to overcome this situation, we must build an complete 3D craniofacial database.

Nevertheless, in the late 2 decades, there are some industrialized countries, such as US. Frence and Japan all had set forth standardized 3D craniofacial models for the design and inspection of protective devices [6],[7],[8]. These 3D models may come from the compromization and consensus of many individual manufactures, because there are many existing 3D craniofacial models which individual manufactures use as the basis for design and inspection. However, these 3D models are too geometrical and simple as compared to the complex surfaces of our skulls and faces. Therefore, it is quite doubtful whether or not these simple models are able to design protective devices which will perfectly fit our skulls and faces, especially respiratory masks.

Knowing that, Institute of Occupational Safety and Health (IOSH) set forth to conduct a 3D craniofacial anthropometry survey. In cooperation with Tsing Hua University, IOSH has sponsored a 2 year research project - **The Study for workers' typical craniofacial manikins**. The object of this study is to build a 3D craniofacial database, from which typical craniofacial manikins will be selected to be used for the design and standardization of personal protection devices, such as respiratory masks, safety helmets and safety goggles.

Methods

Four aspects related to the research methods of this project are described in the following sections, these are sampling strategy, measurement system, and measuring procedure.

Sampling Strategy

This project used 3 stages sampling strategy to randomly draw 1200 subjects from Taiwanese worker's population. The first stage was to draw 16 professions out of a total of 67 from Taiwanese worker's annual population report [9]. The second stage was to draw one company from the selected profession. The third stage was then to randomly draw a proportion of workers to make up a total of 1200 samples.

Measurement System

The measurement system consisted of a 2.5D photo-grating measurement system and a measurement chair. The 2.5D photo-grating measurement system consisted of 4 CCD cameras and 6 LCD grating projectors. These 10 items were installed in a double layer "L-types" structure (see Fig. 1). CCDs were installed in the middle of the L-type-arms. LCDs were installed on the both ends of the arms, noticed that one LCD was redundant. The CCDs were perpendicular to the arm, and LCDs were 45° to the arm. The upper layer was facing 30° downward and the lower layer was face up 30°. The photo axes of these 10 items all pointed to a common focus. The system took a series of 8 localized-area measurements in 94 seconds. These 8 localized area measurements would then be integrated into a integrated image. The integrated image was approximately 100,000 points and is roughly 260° around the craniofacial circumference. The rest of 100° was the un-measurable area which was in the right posterior section of the head, this area was supported by a fixture to stabilize the posture of the head during measurement.

The measurement chair was located in the geometrical middle of the "L-typed" structure and was used to stabilize posture during measurement. The chair was fabricated by 3 items - car seat, high-adjustable base, and a head-support fixture.(Fig. 2)

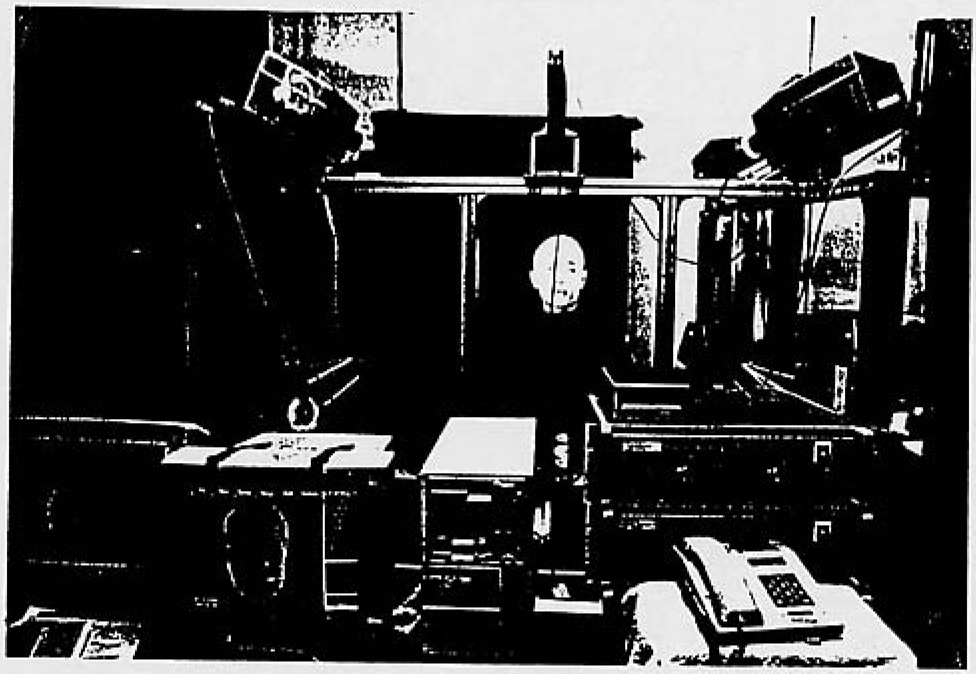

Figure 1 2.5D Photo-grating Measurement System (consists of 6 LCD projectors and 4 CCD cameras).

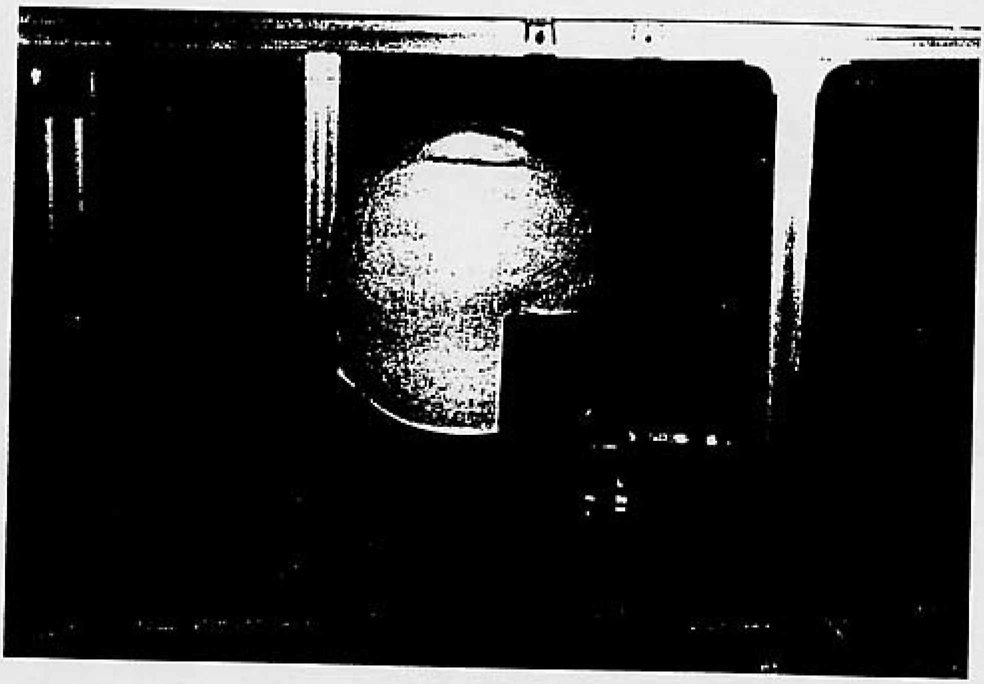

Figure 2 Measuring Chair with the Head-support Fixture.

Measurement Process

The whole measurement procedure could be classified into 2 processes - preparation and measurement. The preparation was to contact the selected company, arrange schedule and place, disassemble measurement apparatus, transport, reassemble, test and calibrate the system. Each relocation took 10-15 working hours, roughly 2 days. The measurement process was to arrange the selected samples in the measurement sites and fill out personal data, such as name, age, sex, height, weight, and type of work etc. Then the samples were asked to wear a white swimming cap. The purpose of the cap were two folds, the first was to press the hair down to the surface of the skull, the second was to enhance the reflection of black hair. Several areas, such as lower posterior aspect of the temples which can not be covered by the cap were applied with white powder. Then the samples were asked to sit in the chair with the head supported by fixture and adjusted to the appropriate location for measurement. The system would take a series of 8 localized measurements in 94 seconds.

Results

A total of 1200 samples have been measured completely, however, after detail inspection during initial stage of data processing, only 1073 samples were effective. Among these data, 702 were males and 371 were females. These 1073 data were then analyzed to yield two types of results, one was 2D measurements, the other was 3D manikins. The deviation and analyses of these data are describe as followed.

Two Dimensional Measurements

These 1073 data were first used to derive 2D measurements. Each of these 1073 craniofacial data were marked with 13 anatomical landmarks on computer (Fig. 3), such as crown (vertex), glabella, left and right ocular angles (Table 1), to yield 24 key measurements, such as biocular breadth or menton to occiput height (Table 2). These measurements constituted a 2D craniofacial anthropometrical database (Table 3).

Three Dimensional Typical Manikins

In a far more complex procedure, these 1073 data were then used to derive series of 3D typical manikins which were used for the design and standardization of respiratory masks, safety helmets or safety goggles. These derivation of 3D typical manikins must proceed through 3 stages : sizing, selection and tooling processes.

The purpose of sizing was to divide these 1073 data target into several size groups [21]. So, each individual would have suitable size of device within reasonably allowance tolerance. The key measurements used for sizing and the number of design sizes required were dependent on the types of devices to be designed. For instance, for helmets, head depth and head width were used as key measurements. Two sizes of helmets - large and small will be enough, because the clearance allowance for helmets is approximately 40mm-50mm and the variation of head width is in the order of 80mm (120mm-200mm), and head depth is also 80mm (140mm-220mm). For the design of respiratory masks, face width and face length

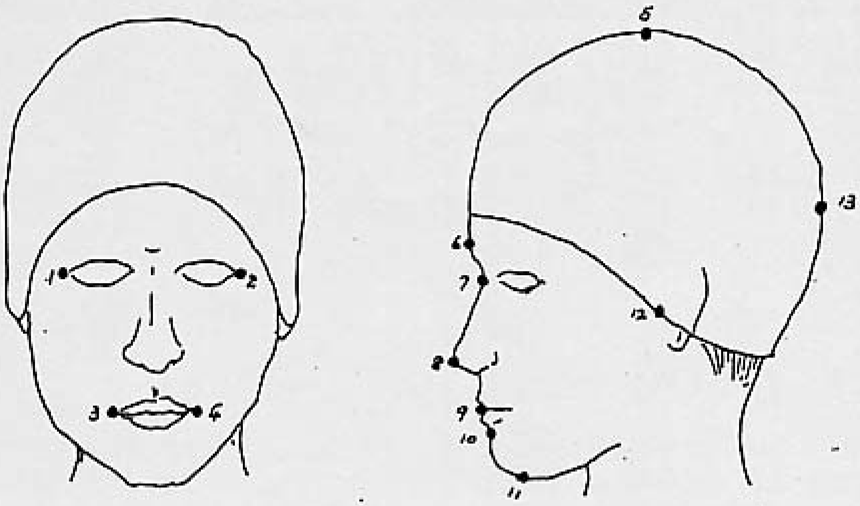

Figure 3 Thirteen Anatomical Landmarks on Face.

Table 1 Thirteen Anatomical Landmarks on Face.

NO	Name
1	Left ocular angle
2	Right ocular angle
3	Left angle of mouth
4	Right angle of mouth
5	Crown(vertex)
6	Glabella
7	Root of nose(nasion)
8	Nasal Septum
9	Lip
10	Sub-lip
11	Chin
12	Tragion
13	Occipital

Table 2 Twenty Four Craniofacial Sizes.

NO	Name	Begin	End
1	Biocular Breadth	left ocular angle	right ocular angle
2	Bi-tragion breadth	left tragion	right tragion
3	Lip length	left lip angle	right lip angle
4	Glabella to top of head	glabella	top of head
5	Sellion to top of head	sellion	top of head
6	Ectocanthus to otobnsion	ectocanthus	otobnsion
7	Pronasale to top of head	pronasale	top of head
8	Tragion to top of head	tragion	top of head
9	Stomion to top of head	stomion	top of head
10	Lower lip to top of head	lower lip	top of head
11	Menton to top of head	menton	top of head
12	Menton-crinion length	menton	crinion
13	Menton-subnasal length	menton	subnasal
14	Menton-pronasal length	menton	pronasal
15	Menton-stomion length	menton	stomion
16	Menton-lower lip length	menton	lower lip
17	Pronasal to tragion	pronasal	tragion
18	Pronasal to wall	pronasal	wall
19	Glabella to wall	glabella	wall
20	Sellion to wall	sellion	wall
21	Lip to wall	lip	wall
22	Tragion to wall	tragion	wall
23	Chin to wall	chin	wall
24	Menton to occiput	menton	occiput

Table 3 Craniofacial anthropometrical database of Taiwanese (1073 subjects, 1995).

NO	Name	Mean	Std. Div.	Min.	Max.	2.5%	5%	50%	95%	97.5%
1	Biocular Breadth	102.83	7.02	80.91	124.42	89.12	91.07	102.76	114.51	116.55
2	Bi-tragion breadth	150.90	11.28	113.86	188.22	127.95	131.80	151.33	168.69	172.52
3	Lip length	60.34	6.67	41.91	81.34	48.03	49.53	60.31	71.39	74.07
4	Glabella to top of head	108.80	10.58	74.17	143.23	87.03	89.69	109.43	125.65	129.00
5	Sellion to top of head	126.75	10.69	92.52	164.29	104.62	108.02	127.65	143.32	146.50
6	Ectocanthus to otobnsion	128.62	9.16	99.69	159.16	110.22	112.83	129.06	143.15	145.72
7	Pronasale to top of head	164.14	11.47	122.14	204.36	140.53	144.81	164.52	182.44	185.92
8	Tragion to top of head	149.81	10.54	116.61	181.31	129.80	133.29	149.16	167.53	170.32
9	Stomion to top of head	200.12	11.45	159.71	238.98	175.41	180.38	200.93	218.57	222.09
10	Lower lip to top of head	217.37	11.31	179.89	257.44	194.12	197.56	217.79	235.36	239.30
11	Menton to top of head	242.77	11.06	209.33	277.28	220.72	223.89	242.87	260.68	264.29
12	Menton-crinion length	133.97	8.34	110.18	162.40	117.86	120.19	134.07	147.69	149.44
13	Menton-subnasal length	116.02	8.03	93.62	146.80	100.63	102.91	115.97	129.11	131.20
14	Menton-pronasal length	78.62	6.99	57.96	126.60	65.84	67.95	78.38	90.29	92.75
15	Menton-stomion length	42.65	5.47	26.96	71.93	32.96	34.78	42.21	52.16	55.58
16	Menton-lower lip length	25.40	4.61	9.31	50.92	17.00	18.27	25.20	33.46	35.32
17	Pronasal to tragion	108.05	9.08	82.38	137.38	90.59	93.22	107.97	123.10	126.58
18	Pronasal to wall	198.13	10.25	155.05	232.64	178.68	180.69	198.48	214.68	218.44
19	Glabella to wall	185.41	9.24	143.26	216.67	168.44	171.25	185.25	200.29	203.03
20	Sellion to wall	179.96	8.78	143.21	212.63	163.30	165.68	180.03	194.01	196.79
21	Lip to wall	183.89	10.68	147.37	230.12	163.69	166.25	183.65	202.05	204.79
22	Tragion to wall	90.08	11.17	46.99	135.18	67.96	71.51	90.46	107.63	110.01
23	Chin to wall	163.31	9.28	126.49	200.11	145.74	148.55	163.38	178.52	181.74
24	Menton to occiput	226.97	14.01	189.58	265.96	201.38	204.64	226.96	249.64	253.55

should be used as key measurements for sizing. Three sizes of masks - large, medium and small - were required to achieve tightly fit requirement within the flexibility of mask materials. Because the flexibility of material is 30mm (±15mm), and the variation of face width is in the order of 80mm (110mm-190mm), and face length 60mm (90mm-150mm).

The sizing methods for helmets and respiratory masks were described as followed. For masks, the face length of these 1073 data were plotted against face width (Fig. 4). The coefficient of correlation was 0.35. The range of face length was between 90mm and 150mm, and face width is between 110mm and 190mm. Each measurement was partitioned at 5mm increment, so as to convert the plot into a 12 by 16 matrix. Since the flexibility of mask material was 30mm, so we used a 30mm by 30mm square as the boundary for sizing. We first decided the medium size by stepwisely move the square on the matrix until an area which covered the largest number of samples had reached (block2 in Fig. 5). Then we stepwisely move the square in the upper right direction, until the area (block1) which yielded the largest samples in union with medium size area (block2). Small size group (block3) was decides in a similar manner. Medium size area covered 843 samples(79%), large size covered 492 samples (46%) and small size covered 284 samples (26%). These 3 sizes covered a total of 1032 people (96%).

In a similar manner, the sizing of these 1073 samples for helmets, was first plotted head depth against head width (Fig. 6). The coefficient of correlation was 0.34. The range of head depth was between 140mm and 220mm, and head width was between 120mm and 200mm. Each measurement was also partitioned at 5mm increment, so as to convert the plot into a 16 by 16 matrix. Since the clearance allowance is 40mm-50mm, we first located an area which would enclose both 97.5 percentile of group head depth and head width and covered the largest number of samples as large size (block 1, Fig. 7). We then located small size area which would enclose both 2.5 percentile of group head depth and head width and covered the largest number of sample as small size group(block 2, Fig. 7). Largest size group covered 853 samples (80%), small size covered 605 samples (56%). These 2 sizes covered 1045 samples (97%).

After the proposed number of sizes was determined, we then selected a typical sample from each size group. The selection of typical sample for helmets was simple and straightforward. What we needed was to select the one who had the largest head depth and head breadth. On the contrary, for masks, we must go through tedious difference comparisons, to choose one sample which yield the smallest "total difference" within the group. Total difference was a measurement of the degree of three dimensional differences of one individual to the rest of the whole group.

In order to compute total differences, we must compute individual differences, to compute individual differences we must compared local differences, before local differences could be compared, we must draw cutting plane continuos in advance. The drawing of cutting plane contours was to cut the 3D integrated craniofacial image by 16 horizontal planes and 13 sagittal planes and draw these cutting plane contours on computer screen(Fig. 8). For a pair of samples, we superimposed each pair of correspondent contours together and compared their areal differences. These differences were called local difference. The sum of these 29 local differences was named individual difference. Within a group, an individual sample had

Face Length (mm)	110-115	115-120	120-125	125-130	130-135	135-140	140-145	145-150	150-155	155-160	160-165	165-170	170-175	175-180	180-185	185-190	Total
145-150										1							1
140-145									2		1				1		4
135-140									2			1	1				4
130-135				1	1	3	2	2	6	6	3	3	2		1		30
125-130					3	3	8	9	21	25	14	13	5	2	1	2	106
120-125	1		1	1	3	13	11	28	39	36	32	12	9	2			188
115-120		2	1	2	8	14	28	47	49	44	36	17	5	2	1		256
110-115	1	2	2	7	11	23	32	44	42	31	21	8	3				227
105-110	2	1		8	12	19	31	26	31	17	14	2	1	1			165
100-105				6	9	9	17	10	5	11	3	1					71
95-100				1	2	5	3	4	2	1			1				19
90-95			1						1								3

Face Width (mm)

Figure 4 Bi-variable Table of Face Length v.s. Face Width.

Face Length (mm)	110-115	115-120	120-125	125-130	130-135	135-140	140-145	145-150	150-155	155-160	160-165	165-170	170-175	175-180	180-185	185-190	Total
145-150										1							1
140-145									2		1				1		4
135-140									2			1	1				4
130-135				1	1	3	2	2	6	6	3	3	2		1		30
125-130					3	3	8	9	21	25	14	13	5	2	1	2	106
120-125	1		1	1	3	13	11	28	39	36	32	12	9	2			188
115-120		2	1	2	8	14	28	47	49	44	36	17	5	2	1		256
110-115	1	2	2	7	11	23	32	44	42	31	21	8	3				227
105-110	2	1		8	12	19	31	26	31	17	14	2	1	1			165
100-105				6	9	9	17	10	5	11	3	1					71
95-100				1	2	5	3	4	2	1			1				19
90-95			1						1								3
Total	4	5	5	26	42	85	132	170	200	172	126	57	27	7	4	3	1073

Face Width (mm)

block1 :	(+)	492	46%
block2 :	(+)	843	79%
block3 :	(+)	284	26%
overlap	(-)	390	36%
overlap	(-)	197	18%
SUM	(=)	1032	96%

	male	female
block1:	433	59
block2:	561	282
block3:	102	182

Figure 5 Size Classification of Respiratory-masks-used Craniofaces :

Block size is 30mm*30mm, the middle size group (block2) includes the largest subjects (843 people, 79%), the small size group (block3) includes 284 subjects (26%), and the large size group (block1) includes 492 subjects (46%).

Head Depth (mm)	120-125	125-130	130-135	135-140	140-145	145-150	150-155	155-160	160-165	165-170	170-175	175-180	180-185	185-190	190-195	195-200	Total
215-220													1				1
210-215									1					1			2
205-210						1		1	1	3	7	2		1			16
200-205					1	1	1	5	10	10	4	6					38
195-200		1		1	2	2	4	14	23	20	19	12	8	1		1	108
190-195			1	4	1	10	20	29	30	35	24	12	7	3	4	1	181
185-190		1	1	4	7	21	23	30	40	35	28	12	5				207
180-185	2	1	1	3	9	18	28	36	47	33	23	9	2	1			213
175-180	2	1		7	16	21	24	24	27	22	10	1	3				158
170-175			2	4	6	11	19	27	14	13	7	2	1				106
165-170		1		2	6	2	7	3	5		2	1					29
160-165				1		1	5	1	2	1							11
155-160							1										1
150-155					1												1
145-150																	0
140-145						1											1

Head Width (mm)

Figure 6 Bi-variable Table of Head Depth v.s. Head Width.

Head Depth (mm)	120-125	125-130	130-135	135-140	140-145	145-150	150-155	155-160	160-165	165-170	170-175	175-180	180-185	185-190	190-195	195-200	Total
215-220													1				1
210-215									1					1			2
205-210						1		1	1	3	7	2		1			16
200-205					1	1	1	5	10	10	4	6					38
195-200		1		1	2	2	4	14	23	20	19	12	8	1		1	108
190-195			1	4	1	10	20	29	30	35	24	12	7	3	4	1	181
185-190		1	1	4	7	21	23	30	40	35	28	12	5				207
180-185	2	1	1	3	9	18	28	36	47	33	23	9	2	1			213
175-180	2	1		7	16	21	24	24	27	22	10	1	3				158
170-175			2	4	6	11	19	27	14	13	7	2	1				106
165-170		1		2	6	2	7	3	5		2	1					29
160-165				1		1	5	1	2	1							11
155-160							1										1
150-155					1												1
145-150																	0
140-145						1											1
Total	4	5	5	26	49	89	132	170	200	172	124	57	27	7	4	2	1073

Head Width (mm)

block1 :	(+)	858	80%
block2 :	(+)	605	56%
overlap :	(-)	418	39%
Sum	(=)	1045	97%
		male	female
block1 :		632	226
		89%	62%
block2 :		311	294
		44%	81%

Figure 7 Size Classification of Helmets-used Craniofaces :
Block size is 40mm*40mm. The upper limit of the large size group (block1) is 97.5 percentile and it has 858 subjects (80%). The lower limit of the small size group is 2.5 percentile and it has 605 subjects (56%).

to compare with the rest of the group, so each individual could have a series of n-1 individual differences. We then summed all of these individual differences to make up one total difference. In a group, all individuals had one total difference. Finally, we sorted these total differences and selected the one who had the smallest total difference. The sorting graphs of large, medium and small typical craniofaces are presented in Fig. 9, 10, 11.

These selected typical craniofaces were next tooled by CNC machine to produce 3D manikins. These 3D manikins make us visualize the 3D surface of the cranioface easily, and make the design and standardization of protective devices much effective and easier. To produce 3D manikins, we then converted the data into CNC readable format and to design tooling path. Due to the complexity nature of our craniofacial and the capability of CNC machine, each manikin should be cut into two pieces, one anterior side and one posterior side for tooling (Fig. 12, 13, 14).

DISCUSSION AND RECOMMENDATIONS

This study had tried to use the newly developed 2.5D photo-grating measurement system to build an craniofacial anthropometrical database, based on this database, typical manikins were produced for the design and standardization of safety helmets and respiratory masks. 3D anthropometry is able to portrait the complex details of human body surfaces better, and is therefore much better than 2D anthropometry. Nevertheless, three dimensional anthropometrical measurement is very difficult because it should be able to complete the measurement process within a duration of which the postural changes and skin movements are neglectable [11], [13], [14], [15], [17]. The duration is in the order of 1/15 seconds and 5 seconds depending on the area to be measured and precision requirements. In recent years, many advanced 3D measurement system are barely fulfill the requirements. 2.5D photo-grating measurement system is one of the most suitable system for anthropometrical system [19]. However, because this system is newly developed and we used it right after its introducing to the market, there are not many similar researches available to refer to, therefore it is far from perfect and need to be improved.

The aspects of measurement methods need to be improved are measurement speed and the white swimming cap. Although the measurement speed of the system is very fast, it still takes 94 seconds to complete the whole measurement. In a duration of 94 seconds, our posture will change and our skin will move substantially. In order to stabilize the posture, we have to provide a supporting fixture in the left-posterior aspect of the head. In doing so, the surface in this area is unmeasurable. This is a significant drawback. If we could speed up the system and reduce the complete measurement time within 5 seconds, we didn't need any supporting fixture to stabilize posture, moreover, we could make a complete 360° measurement easily by adding two more LCDs and two CCDs.

The second aspect needs to be improved is to make a better fit swimming cap. The most ideal white swimming cap we could purchase from the market could only cover the upper portion of the head and leave a large portion of hair uncovered. These areas are the lower portion of the posterior side and temples etc.. Although these uncovered areas were applied with white power, the results were still poor. If we were able to elongate the rear portion of

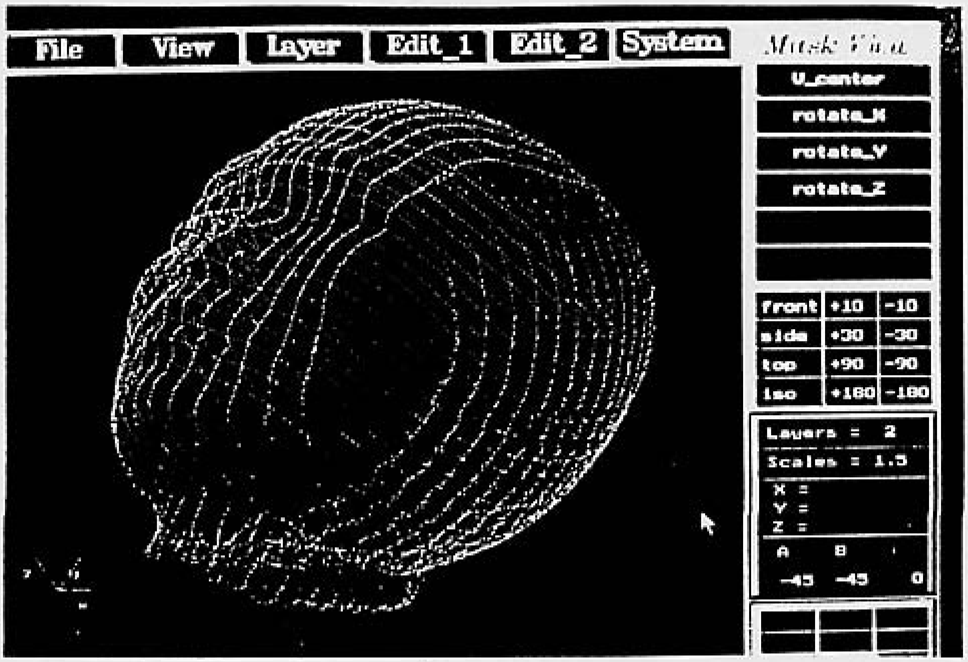

Figure 8 Sixteen Horizontal Cutting Planes and thirteen Sagital Cutting Planes Choosed in Comparison of Craniofaces

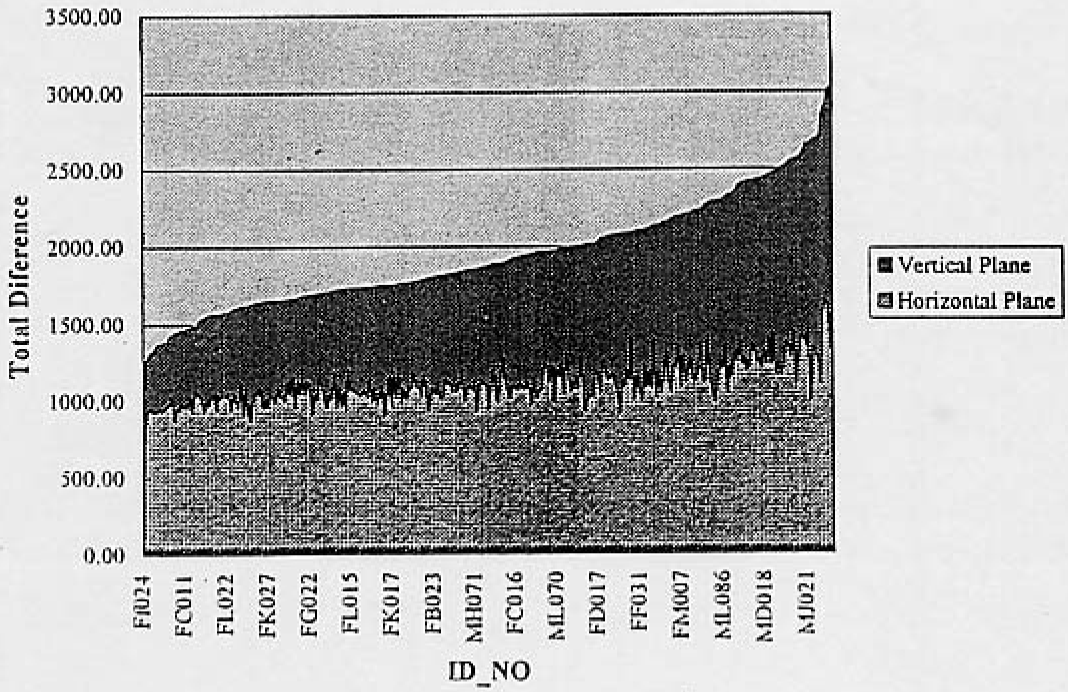

Figure 9 Sorting Graph of Comparison Differences for the Small Typical Cranioface (subject's ID_NO is FF024).

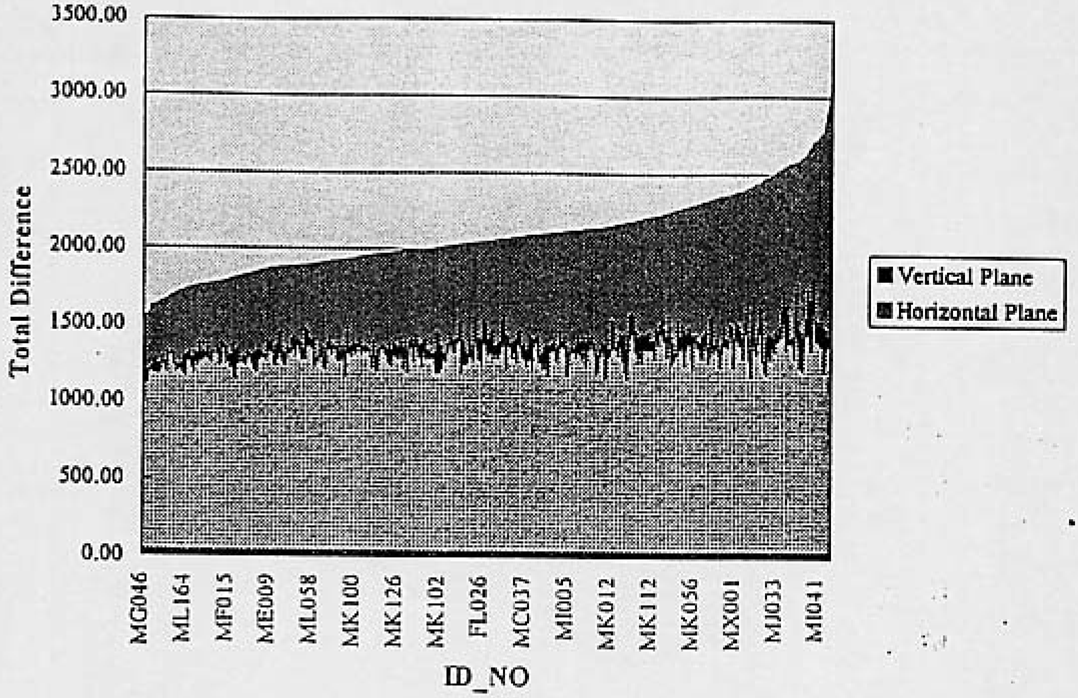

Figure 10 Sorting Graph of Comparison Differences for the Middle Typical Cranioface(subject's ID_NO is FK026).

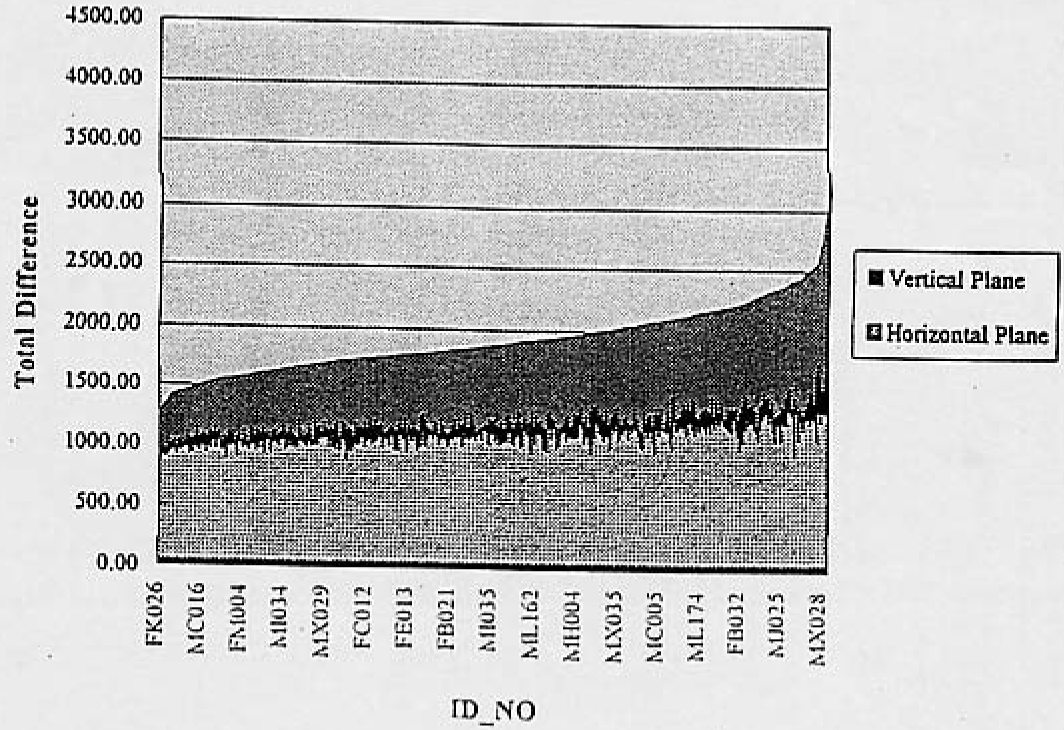

Figure 11 Sorting Graph of Comparison Differences for the Large Typical Cranioface (subject's ID_NO is MG046).

Figure 12 Two Pieces of CNC Tooling Path for The Typical Cranioface.

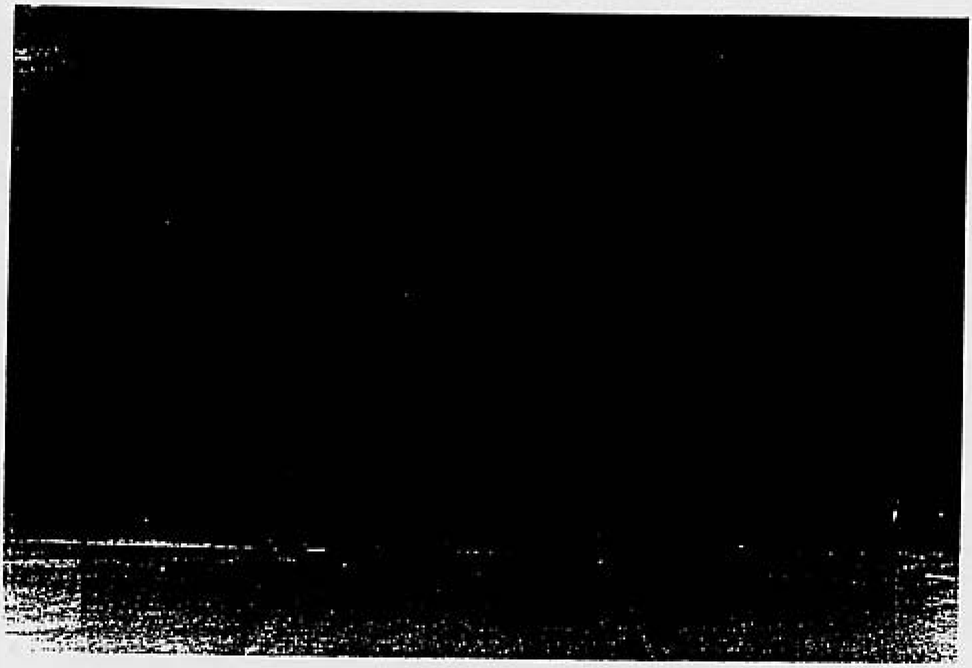

Figure 13 Three Typical Craniofaces for the Design of Respiratory Masks .

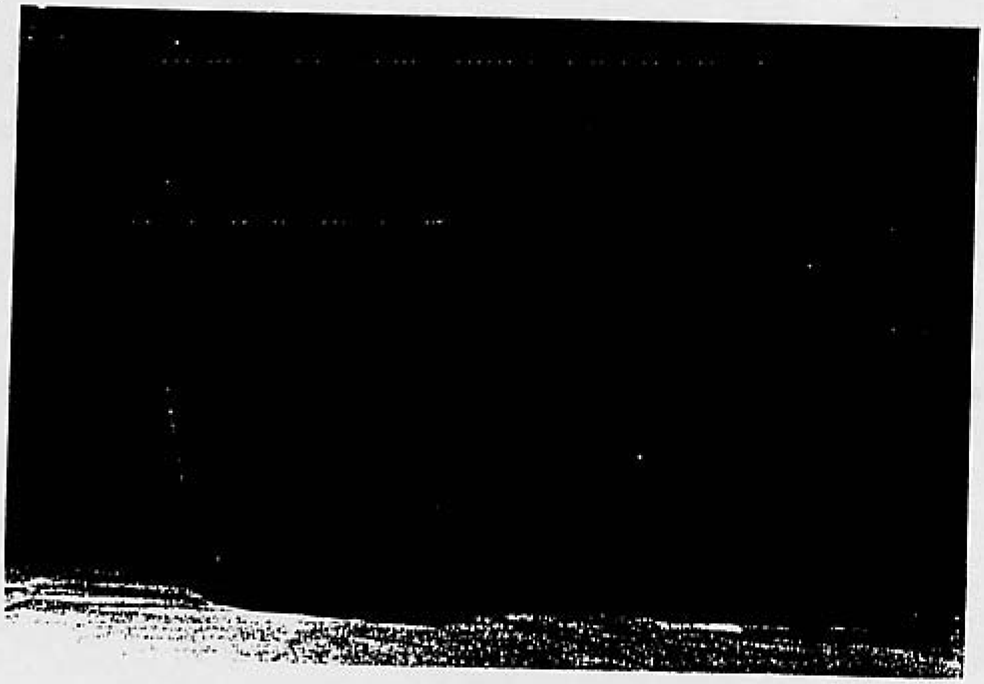

Figure 14 Two Typical Craniofaces for the Design of Helmets .

cap, and two side strips to cover the temp. These enlongations are tightened under the lower jaw. Then we can continuously improve the measurement quality.

In spite of the two imperfections of this measurement method, this study had completed a 1073 3D craniofacial database, and selected 2 series of typical craniofacial manikins to be used for the design and standardization of respiratory masks , safety helmets. Other than masks and helmets, this database would have many other applications. Beside these practical results, the use of using 2.5D photo grating measurement system have made 3D anthropometry very fast, accurate and easy. It is foreseeable that this measurement method will become the main stream in future anthropometrical studies.

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