Constructing Ergonomic Safety Modelling for Evaluating New Designs of Child Car Seats

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Abstract. The safety and ergonomic compatibility are the most important parts for designing child car seats. Since the children, especially the infants, cannot objectively express their aptitudes of safety, comfort and opinions very well, they cannot be suitable subjects for ergonomic design experiments. Applying computers to simulate human motions for solving ergonomic design problems has been explored for many years, especially in substituting real human engaging in high risking tasks. However, in some specific fields of product design, intelligent man-machine (abbreviated as IMM) models suitable for designers are scarcely studied. The main purpose of this paper is trying to construct a totally new IMM model to aid designers of child car seats in the process of evaluating their new design concepts. The new computerized child model with self-adjusting functions can be fitted to car seat designed by any designers. The designer can maneuver the model to understand the potential design risks and ergonomic compatibility, and then improve his design.

Keywords: Child, belt design, solidwork.

1 Introduction

One goal of artificial intelligent research in design is to try to characterize the design process in enough detail that systems can be built more easily, that design knowledge can be acquired more easily, and that design tools can be matched to design problems (Chen et. al., 2006)[1]. Many people would agree that the general flow of design could be characterized by requirements formulation, analysis synthesis, ideation and evaluation (Lai, 2009)[2]. Design in any domain requires evaluation. If we can describe the essential characteristics of this reasoning skill, including the knowledge used and the process, then this can be more easily implemented for any domain (Gero and Sanders, 2009)[3]. Design evaluation can be more effective and more accurate by building useful Intelligent Computer-Aided Design (IntCAD) systems (Brown, 2007; 2009)[4,5]. Systems can range from autonomous design tools, that when given requirements will produce designs, to design aids that interact with a human designer (or designers) to support the design activity (Liu and Brown, 2009)[6]. According to the above previous studies, this paper is focused on searching for an intelligent man-machine model system to assist the child car seat designers to evaluate their new

V.G. Duffy (Ed.): DHM/HCII 2013, Part I, LNCS 8025, pp. 338–347, 2013.

designs more accurately and more effectively by integrating the knowledge of artificial intelligence, design methodology and ergonomics.

There have been many computerized human models for the use of product designers. But most of these are two-dimensional models for adults that cannot be used for the specific use of child car seat designers to evaluate the safety and ergonomic compatibility of their new design concepts (Frank and Marach, 2008;)[7]. The related studies on man-machine models to evaluate the spatial layouts and ergonomic safeties, which may need to employ the knowledge of artificial intelligence, are just in the stage of starting point (Joseph, 1999)[8]. Therefore, this paper aims at applying the knowledge of artificial intelligent techniques; design methodology and anthropometrical engineering to create a new man-machine model that can intelligently evaluate the new design concepts, which is a rather essential design activity for the child car seat designers (Miller, 1998)[9]. This new intelligent model should be operated friendly for the future designers to achieve the final goal of seeking most efficient and effective design functions for the whole man-machine system.

In the current study, the intelligent new model is tried to simulate the designers' behavior to evaluate new design concepts of child car seat efficiently and effectively. Therefore, main purposes of the new model should include the following:
According to the present anthropometrical data of domestic children to build standard child models for observing and simulating child's restrictions and ranges of activity in the car seats, and to provide the designers the principles, standards and suggestions of ergonomic design.

According to the constructing types of present child car seats in use to build standard child car seat models. Due to the domestic makers still don't have the car seats specifically made for Taiwan children, the seat models are built from abroad.

Using the method of computer simulation to build an intelligent man-machine (abbreviated as IMM) model for the study of man-machine interface, and to provide designers to observe the child's static visibility, motion range simulation and dimensional restrictions in the car seat, and then to assess the ergonomic compatibility of their new designs and to revise them accordingly.

Realizing the above main purposes, research procedures of this study can be depicted to study the basic anthropometrical data of children, and then to build standard child models accordingly, to study the typical constructing components of child car seat, and then to build standard safe seat models accordingly, to explore the conventional computer simulation models and to assess them carefully, to construct a new computer program for the IMM model to simulate the evaluating behavior of child car seat designers and operating the new developed intelligent model by potential model users and improving it afterward.

2 Basic Study

2.1 Analysis of the Anthropometrical Data for Children

The construction of human model for child safety seats involves extensive anthropometrical data, including physiological developing characteristics, static body measurements and dynamic body measurements of child. This part of anthropometrical data had been finished by the author in 1999(Lai and Chang, 2007; 2009)[10,11]. The data used in this study are the children aged ranging from one-year to three-year.

2.2 Analysis of Safety Seat Components for Children

The child car seats, also called as child restraint device for automobiles, are suitable for the use of children to avoid or reduce the injuries during car accidents. This study is focused on representing the relationship between man and machine models, and the interference with each other. Thus, in order to build the man-machine model, the understandings of individual components and functions are needed. Figure 2 shows the individual components of a typical child car seat, which conforms to the standard classifications of China National Standard (CNS 11497). Functions and individual components are defined as the following:

1. Child safety belt: It is composed of weaving belt, buckle and length adjuster to restrain the child, and is a part of protection devices.
2. Assistant safety belt: It is to protect the child car seat from sliding and to make the protection device more stable by adding a fixed safety belt from the back support of the seat.
3. Buttock support: It is one part of protection device to support the child's buttock.
4. Back support: It is also one part of protection device to support the child's back and head.
5. Lateral support: It is a part of back support to protect the head against moving horizontally.
6. Contact surface: While fitting up the child model to the protection device, the entire surfaces surround the head and human body of child model.
7. Top slots: These are the slots to make the safety belt to go through the rear side of car seat.
8. Bottom slots: Functions are the same as top slots. Children can use different height of slots in accordance with their stature.
9. Shoulder straps: These are safety straps, which mount the shoulder through the frontal body, to fix child's shoulder.
10. Buckle: It is used to tighten the safety belt.
11. Crotch strap: This is a safe strap to jump over the child's hips.
12. Harness adjuster: It is used to tighten the shoulder belt, which is adjustable and generally possesses a lock device.
13. Frontal railing: It is a cushion device to protect the child from turnover and causing injuries.

3 Method to Construct the IMM Model

The construction of IMM model should include building standard child models, standard child car seat models, and connecting program to simulate the designers' designing behavior such as testing the man-machine interface, and adjusting the child model or the child car seat model to calculate the safety factors and ensure the design security. The following analyzes the algorithm of model constructing procedures.

3.1 Defining Environmental Parameters

The IMM model intends to demonstrate that a standard child model can fit for typical child car seats, as well as simulate the man-machine static vision, the effects of motion range and anthropometrical restrictions. Hence, before to construct the model system, the following man-machine environmental parameters must be defined.

Standard child models are in accordance with the anthropometrical data of children aging from one-year to three-year old, and without distinguishing gender.

Typical child car seats models conform to the children aging from one-year to three-year old and with frontal forward type.

The vertical centre of child models aim at the vertical centre of car seat models, and fit the child models to car seat models in order to make the back and the thighs of child models to contact the back-support and buttock-support of car seat models, respectively.

The initial state of child models is that the upper arms hand down lateral sides of body, and forearms and upper arms with an angle of 120 degrees, heels of both feet with vertical state, as well as lower legs and thighs stretch horizontally forward.

Child models are in accordance with normal movement ranges and anthropometrical restrictions. And designers can observe and perform the evaluation of ergonomic compatibilities of motions and activities of child models.

3.2 Building Standard Child Models

Basic skeletal frameworks of standard child models are built on the basis of body links, with the programming language of Visual Basic 6.0 and the support scripts of computer package 3DS MAX.

3.2.1 Parameter Control of Child Models

While constructing body's and limbs' dimensions and considering the characteristics of children's development, the standard child model is divided into 14 body segments and 13 joints (Huang, 1995)[12]. These body segments consist of head, body torso, left upper arm, left forearm, left hand, right upper arm, right forearm, right hand, left thigh, left shank, left foot, right thigh, right shank and right foot. The corresponding areas are shown in figure 1. The construction of overall size is in accordance with the surrounding profiles as shown in Table 1. The overall size is used for the evaluation of restrictions on the range of activities.

3.3 Building Standard Child Car Seat Model

SolidWorks is a well-developed software for constructing physical models, since it includes the function of geometric numerical data transformation and supports the program developing tools for Visual Basic and Visual C++. In order to construct an ideal seat model to conform to the dimensions of child car seat and to provide the function of spatial man-machine interference analysis, Solidworks is employed in building standard child car seat models.

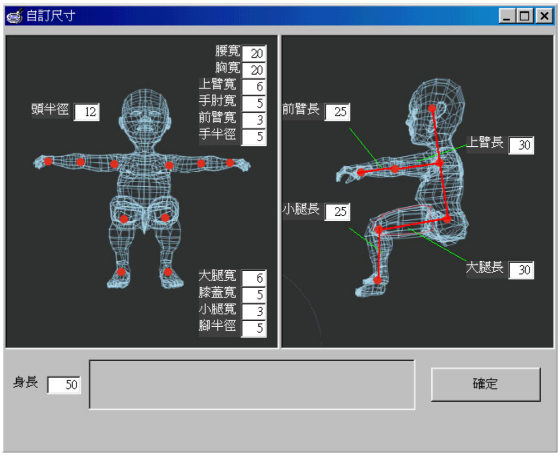

Fig. 1. Child model used for car seat designers in this study

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Table 1. Measuring items of standard child model

Class	Type of item
Basic measures	Age (1,2,3 year-old)
Linear dimensions	Head width (95th%le, 5^{th}%le)
	Head length (95th%le, 5^{th}%le)
	Upper arm length (95th%le, 5^{th}%le)
	Forearm length (95^{th}%le, 5^{th}%le)
	Tight length (95^{th}%le, 5^{th}%le)
	Seat height (95th%le, 5^{th}%le)
	Acromionheight(95th%le, 5^{th}%le)
	Width between two elbow (95th%le, 5^{th}%le)
	Elbow height (95th%le, 5^{th}%le)
Thickness (surrounding length)	Upper arm thickness (95th%le, 5^{th}%le)
	Forearm thickness (95th%le, 5^{th}%le)
	Chest thickness (95th%le, 5^{th}%le)
	Tight thickness (95th%le, 5^{th}%le)
Range of joint activities	Left and right leaning of head
	Rotation of neck
	Bending of elbow
	Arm stretch, external spin and internal spin
	Elbow flection
	Shoulder raising
	Shoulder flection and stretch

3.4 Simulating Man-Machine Interface and Adjusting Models

The following infers the algorithm of this new type of simulation method to analyze the spatial interface of child model and child car seat model.

3.4.1 Method of Removing Back Face

The method of object space to identify the back of object is based on the following equation of plane.

$$Ax + By + Cz + D = 0 \quad (1)$$

Any point (x', y', z'), described at right hand coordinating sysem, if satisfied the following inequality:

$$Ax + By + Cz + D < 0 \quad (2)$$

Then this point is inside the plane. If the point (x', y', z') is an observing point, the plane satisfied the inequality (2) has to be the plane, which cannot be seen from the observing plane.

Table 2. Seat components and man-machine interference range

Name of component	Parameter	Range of man-machine interference
Seat back support	Area (length × width)	Head width, seat height, width of two elbow, acromion height, elbow height
Slot (upper, middle and lower)	Height of slot and width to the center of seat back support	Acromion height, chest thickness
Seat buttock support	Area (length × width)	Buttock width, thigh length
	Angle between seat back support and buttock support	Bending angle of waist
Lateral protective rack	Length, width and thickness	Left and right leaning of head, neck spin, acromion raising
	Angle between lateral rack and seat support	Left and right leaning of head, neck spin, arm stretch, external spin and internal spin
Frontal protective rack	Position of rotating axis	Arm stretch, seat height
	Arm length of rotating axis	Arm flections, seat height
	Length, width and height of frontal protective rack	Chest thickness, shoulder flections and stretch

3.4.2 Method of Scanning Face Line

This kind of object space method to remove the hidden plane is the extensions of scan line algorithms used by the inner part of polygon. Figure 2 demonstrates the principles of scan line method. Firstly, we define each plan a flag, which can be set as on or off, to represent the position along the scan line being faced inside or outside.

The plan with the most left margin is on, and the most right margin is off. The scan line handles from left to right. The intersecting sides of scan line 1 are AB, BC, HE and FG. Along the scan line 1 and at the position between sideline AB and BC, there is only a flag of plane S1 being on. Thus, there is no need to calculate the depth and input the numerical data of S1 to renewing buffer. Similarly, there is only a flag of S2 being on between HE and FG. The scan line 1 does not intersect with plan in other positions. Thus, intensity values of other region have to be set as background intensity. The sidelines to be past through by scan line 2 and 3 consist of DA, HE, BC and FG. Along scan line 2 and between DA and HE, there is only a flag of S1 being on. But between HE and BC, the flags of two planes are all on. That shows the depth must be calculated with the coefficient of two planes. Condensing method can be utilized from one scan line to the next scan line. There is no change between the intersection of scan line 2 and 3. These two planes must be the same directions determined by scan line 2. Any amount of overlapping polygon can be handled by this kind of scan line method. Flags of surface plan have to be set to indicate one position to be inside or outside. While calculating the depth, the mutual cover situations are reconsidered.

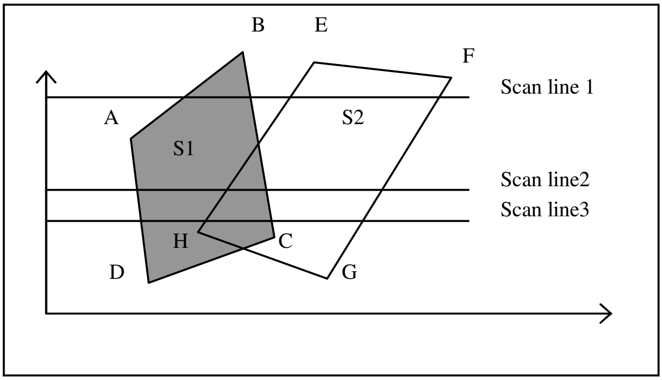

Fig. 2. Descriptions of scan line method

3.4.3 Method of Solving Spatial Intervention of Man-Machine Models

According to the extensions of the above two algorithmic concepts, to judge the mutual positions and relative relationships of two objects in the space, the coordinating system has to be defined in the space world of the objects. That is a fixed system as well as a view coordinate and a local coordinate, so as to perform transformations in comparison with relative positioning relationships among the objects themselves. The objects are constructed in sequential polygon form and have completely polygonal order as well as numbered coordinates. Employing the tool of 3D Max Studio script, component positions of each object are grouped, so as to reduce the frequencies of interferences. Depending on the established plan equations of every polygon and according to the algorithm, the judgment is proceeded with to eliminate the polygonal region, which is not interfered in the external part of a plan. In order to understand the belonging parts of objects and to become the concluding basis of ultimate interference model, before restoring the object positions, the relative object polygon and original object polygon are calculated including their intersecting points, vertical distances in accordance with the plan equations. According to the above principles, a child's head model is constructed in the current research to analyze the interferences and to understand the calculation capacity as well as the program-judgmental capacity. This will be the basis of developing the IMM model.

4 System Operation of the IMM Model

In order to have the designers more conveniently to make use of this man-machine model, a friendly user interface is provided for designers' easy operations. The picture of computer man-machine system can be divided into four views including child model view, car seat model view, man-machine model view and control parameters view. First of all, the needed parameters were set up, then the program was performed, three views appeared each model. The designers can adjust action parameters in the view of man-machine model. After each adjustment, spatial interference model is calculated. Accordingly, designers can evaluate the ergonomic effectiveness and user compatibility of new design car seat, as shown in figure 3.

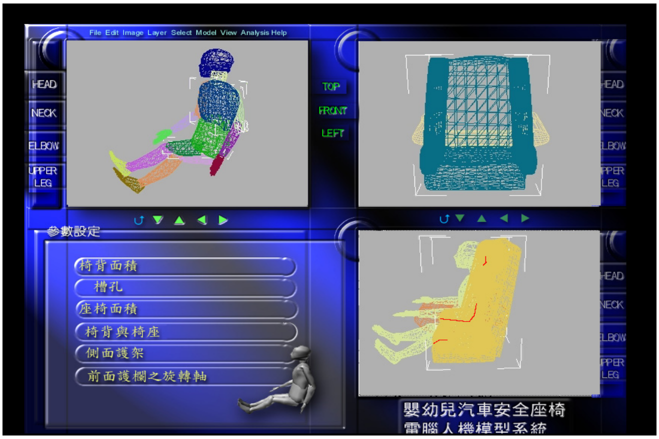

Fig. 3. System applications of the IMM model

5 Conclusion

The establishing of this IMM model will reduce the cost of making the physical model and avoid the risk hazards of child's testing as well as shorten the time of car seat model design and accurately evaluate the ergonomic compatibility and suitability of a new man-machine system. This is a new attempt in the related fields of artificial intelligence to apply the knowledge of computer simulation, spatial interference with programming analysis and ergonomic compatibility and usability to evaluate totally new product designs. Although every steps of building the IMM model system is very trivial and delicate, triviality and delicacy are the requisite for accurate evaluation for car seat design. Therefore, this new attempt of achieving the application of the related artificial intelligent knowledge and ergonomic design methodology to construct a totally new IMM model for the accurate evaluation of complicated child car seat designs has been proved to be very practical and feasible for current designers in this digital design era.

Acknowledgment. The financial support of National Science Council in R.O.C. is very appreciated (Project code: NSC98-2213-E006-029). Ms. Yu-Tian Lian also does a plenty of work to assist to build the new model and simulate the new system. Her helpings are very grateful. In addition, the children and their parents, who are invited and recruited as subjects by the doctors and nurses of pediatrics department at Medical Centre of National Cheng Kung University, enthusiastically participated in the anthropometrical measurements are also very thankful.

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