# Computer Aided Ergonomic Design of Helmets Using Biomodelling

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## ABSTRACT

Ergonomic design examines how well products, workspaces, and environments suit the people who use them. A usable design makes intuitive sense, and is physically compatible with the human body to promote productivity, safety and comport. This paper outlines the ergonomic design issues with respect to the design of helmets using bio-modeling. In this design approach, bio-modeling of a skull and a helmet modeling are interfaced with a reverse engineering method to develop a cost-effective way for the design of helmets with ergonomic fit to promote safety.

**Keywords:** Ergonomic design, bio modeling, helmet modeling, reverse engineering.

## 1. INTRODUCTION

The effectiveness of crash helmets for motorcyclists has been studied for decades, and they are known to reduce the risk of severe head injury by about one-third. Estimates from good studies show that the reduction in risk of head injury as a result of wearing a helmet is in the order of 45 per cent. Depending on the type of impact and the severity of injury, the reduction in the risk of head injury as a result of wearing a helmet has been shown in several studies from all over the world to be in the range of 45 to 85 percent [1.2]. More recent sophisticated statistical analyses of the biomechanical and epidemiological evidences in the United States show that crash helmets reduce the risk of fatal skull injuries, and a reduction in the risk of being killed was around 30 per cent [3-5].

Injuries to the scalp, skull and brain may be inflicted by a variety of mechanisms, and to protect against these different mechanisms requires a variety of approaches. The two fundamental principles for helmet design are centered on the use of padding to absorb energy and on the distribution of impact loadings. Generally, helmets cushion the blow. The foam it is made of crushes, and does not bounce back. It just gets thinner and the head slows down gradually. The plastic on the outside keeps the foam from breaking up and providing sliding motion on the pavement and jerk your neck. The helmet actually stopped the head in about six milliseconds (thousandths a second) and the brain is not subjected to reach the injury threshold. But if the helmet is absent, the impact is stopped in less than one millisecond and the brain reaches the energy threshold. Hence with a helmet, the energy spike is stretched out over six milliseconds and without a helmet the impact goes to brain in less than one millisecond. Because energy cannot be created or destroyed, it must be transferred or absorbed. Therefore, the basic aim of head protection is to reduce the forces that could injure the head by absorbing some of the kinetic energy through the deformation or destruction of something else. That is the function of the protective helmet. The extent to which the forces generated at impact can be reduced is a function of how much deformation of the helmet's structure may be achieved and the force required for that deformation. This in turn will depend on the strength, the amount and the shape of the padding material and on its relationship to the head. Padding materials may be categorized either as plastic or elastic. If padding is plastic, it will not recover from any deformation that occurs during impact loading. If on the other hand the padding material is elastic, it will recover its original shape. As it does so, the head will resume its initial velocity but in the opposite direction (in other words it will bounce). The maximum force developed will be the same, but the time during which the head is loaded will be doubled. Most padding materials are neither perfectly elastic nor perfectly plastic, and the selection of material will depend to some extent on the activity, which threatens the head.

One of the primary objectives of good helmet design is to maximize the area of padding that can interact with the head during impact. This is because maximizing the amount of material used during the impact maximizes the absorption of kinetic energy and thereby minimizes the transfer of energy to the head. A well fitting helmet will maximize the contact area between head and padded liner. No known form of head protection can completely protect the wearer against all foreseeable head impacts. Even the best available padding material has a definite limit to its energy-absorbing capability. No material can crush more than its original thickness and when a material is nearly fully crushed, it will become very stiff and the forces then developed will become very high. At that point the unabsorbed energy will be transferred to the head.

Improvements in head protection are needed with increased padding thickness, increased padding area (especially over the area of the temples), decreased and uniform crushing strength of the padding. The first two of these properties will maximize the amount of energy absorbed, and the second two will minimize the force developed. The basic constraint known to all helmet wearers and manufacturers is that there are some practical limits to the thickness of padding in a helmet. So the only parameter to maximize the amount of energy absorbed is to increase the padding area. This mainly depends on the contact area of the helmet. But in the market, only standardized helmet shapes and sizes are available which does not account for maximum contact area or an ergonomic fit. Recognizing the deficiencies of maximum contact area in commercial helmets, customized protective headwear is a must for high-speed environments.

In the design of helmets, the fundamental principles are centered on the use of padding to absorb energy, and the distribution of impact forces. A well fitting helmet will have maximum contact area between the head and padded liner to increase its energy absorbing capacity in order to minimize impact forces to the head. The readily available standardized helmet shapes and sizes do not usually make a good fit for all people. Bio-modeling of a skull to which the helmet is to be designed can lead to ergonomic fit to improve safety and comfort [6,7]. This paper presents an outline of computer-aided design approach in which bio-modeling of a skull and helmet modeling, are interfaced with a reverse engineering method.

## 2. BIO-MODELING

Long since the history of arts, mankind has been immensely interested in capturing human models. With eminent artists cloning human anthropology in realistic 2D paintings, there has been great inclination by the sculptors towards creating such 3Dmodels. This is evident from clay models and statues available in the museums around the world. With the industrial revolution and digital revolution in last two centuries, it is the turn of enterprising engineers to create artistic models. With spurt in new technologies coming up in CAD/CAM sector, new application areas are probed. One such area is the application of the human models for comfortable engineering popularly called as ergonomics. With promising future in ergonomic designs, the digital era is witnessing huge potential for blending the digital technology in enhancing conventional engineering. Nowadays, proven computer aided product development techniques are used for bio-modeling [6]. With the revolution in 3D modeling and interfacing techniques, accurate modeling has become a reality. Initially, dead bodies and human like models are reverse engineered to generate 3D models. These models are used for graphics and animation systems [7]. With the accuracy of the reverse engineered models not matching the expected range, new algorithms are developed [8]. With rising demand for ergonomic designs, conceptions of capturing live models were evolved. Optical light technique was used to scan live humans to create 3D human models [9]. CAD interfacing with medical imaging data has foreseen paradigm shift in bio-modeling hurdles. With accurate data represented in medical images, the CAD version of these data's represents a real 3D model of the body. Realizing the bio-models through rapid prototyping technique has witnessed a radical change in engineering and medical field. The review of the various medical imaging techniques from computerized tomography (CT), Helical CT scan data, magnetic resonance imaging (MRI), X-rays and Ultra sounds and their suitability for RP based bio-models signal a great epoch ahead for mankind [10].

The widely used bio-modeling application is the construction of highly precise custom-made implants using computer-aided subtraction process of three-dimensional CT data [11]. The bio-models can be applied in surgical planning and simulation [12]. Gross et al [13] has reviewed the principles of micro -computer tomography and micro-magnetic resonance imaging in 3D bone construction which is used in the pre-clinical studies on bone diseases and in the investigation of animal trials on new pharmacological compounds active on bone. Computed tomography, computer graphics, and stereo lithography have been used to create entirely new noninvasive methods of fossil reconstruction and morphometry [14]. Zur Nedden et al [15] have applied bio-modeling technique to preserve the fragile mummy, as noninvasive and nondestructive as possible. Vanezi et al [16] have used facial reconstruction from 3-D computer graphics as a routine procedure in forensic cases, as well as for skulls of historical and archaeological interest.

## 3. DESIGN METHODOLOGY

### 3.1 Skull Modeling

Bio-modeling is the creation of full size, physically accurate anatomical models using data obtained from Medical Scanners (CT, MRI, X-RAY, Ultrasound), Conversion software is used to read in reconstructed 2D images obtained from the CF Scanner. The data is converted to produce a STL file, which is used to generate machine code to drive the FDM machine, and create the physical prototype. Creation of bio-models from medical image data is done in two phases.

In the first phase, careful observation of the medical images reveals that 2D cross sectional views of the human skull is captured. The peripheral contours are determined by the edge detection techniques and all the cross sections are stacked. The inner regions are interpolated and result in a 3D point cluster. Normally the head is scanned in cross sections at uniform intervals along vertical directions. Six to ten cross sections are obtained for a normal scan, which will induce a minimum radiation exposure. The cross sections are stacked as planes one by one at equal distances in CAD/medical image interfacing software. The peripheral contours of the cross section images are determined by the edge detection technique and all the cross sections are lofted and connected along the peripheral contours to produce a 3D view. The accuracy of this 3D model depends on the minimum distance between the cross section planes, which in turn depends number of cross section planes to be scanned for a head. For more accurate models, the number of cross sections scans should be more (approximately of the order of fifty scans). This eventually increases the radiation dose exposure to the human, which will lead to dire consequences. Hence a compromise has to be reached.

In the second phase, the 3D point cloud is exported into any CAD soft wares. Lines are drawn through the points and polygons are created. From this polygon model, surfaces are created. Surface smoothening techniques are applied to patch the irregularities and a solid model is evolved. Thus a solid model of the skull is made ready.

### 3.2 Helmet modeling

Commercial helmets vary largely in sizes and are limited to two or three shapes only. Hence customers are forced to select any one of the shapes and appropriate size which may give a feeling of fitness. But on analysis, it is found that only the foam which gives a fit feeling rather than the shell. Hence the padding area or contact area is less than the achievable maximum to withstand loads. In our method, we propose a helmet model where there is no change in the exterior shape, yet the interior surface of helmet is derived from the contours of skull as shown in Fig.1. Hence each person will have a customized helmet with maximum contact area that can bear more loads. In this context, the following are set of guidelines developed for a helmet to adopt the new design:

(i) The helmet should have a minimum thickness throughout the contour of the shell.

(ii) For better manufacturability, the interior surface along the shell is smoothened to minimum degree of fineness.

### 3.3 Conceptual Design Method

(1) Obtain a medical image data of a head (CT/MRI/XRAY/Ultrasound).

(2) Use CAD/medical image interface for conversion of medical image data into 3D solid model.

(3) Reverse engineer half section of a helmet.

(4) Process the point cloud data to generate a 3D solid model the helmet.

(5) Super impose the skull and helmet at the center axis and align them.

(6) Perform Boolean operations to capture the outer surface of a skull as inner surface of the helmet.

(7) Smoothen the interior surface to achieve minimum manufacturing difficulty.

(8) Make offset of the interior surface to provide a clearance for cushioning material.

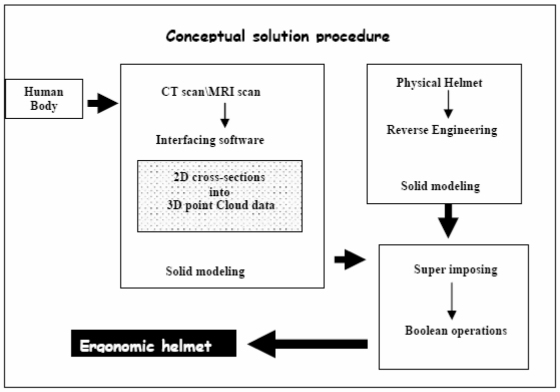

Fig 1: Conceptual solution for ergonomic design

Due to the nature of health hazards associated with CT Scanners, a safe radiation dose has to be observed, and therefore the most accurate images that can be obtained are still cross sections taken at approximately one-millimeter intervals. Also due to the high cost involved in obtaining the required CT scan data, bio-models are still treated at research level. Since the CAD/medical image interface software is in the incipient stages, the cost of the software is very high. Hence most of the academic institutions are not able to afford it. With the above limitations, an alternative design approach was developed to realize the conceptual model.

### 3.4 Alternative design method

The second phase of the scan data conversion is analogous to the reverse engineering method as shown in Fig.2. Thus the output of the medical image interfacing software is a 3D point cloud data, which is the output of the reverse engineering method. From this similarity, an alternative conceptual model was developed using a reverse engineering method as shown in Fig.3.

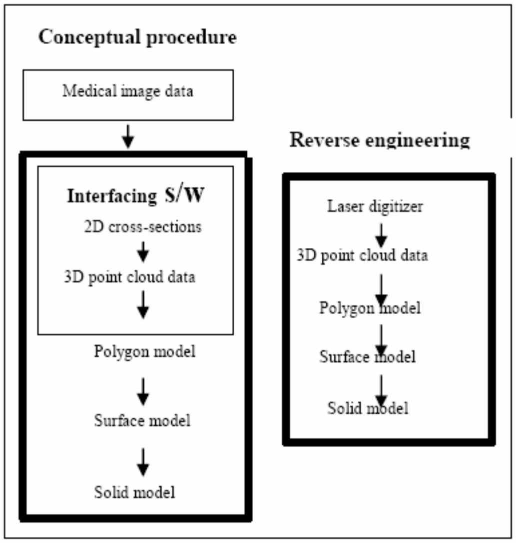

Fig 2: Conceptual model vs. Reverse engineering

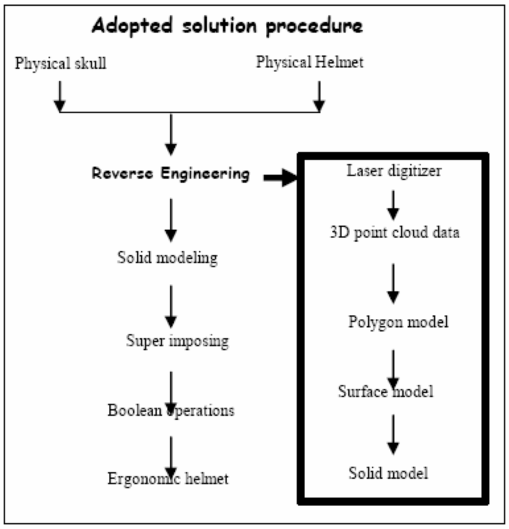

Fig 3: Adopted solution procedure for ergonomic helmet

In this design approach, a skull was placed inside a laser-digitizing machine from Rolta Inc., having an accuracy of 50 μm, as shown in Fig. 4. These scanning views were taken and merged through the software to obtain a 3D model. Initially, the skull with 10,000 data points was obtained to study the surfaces and fineness of the contours, as shown in Fig. 5. It was found that the model was least accurate in its representations. The model was refined with 50,000 data points, and 1, 25,000 data points. Still the contours were not satisfactory for accuracy. Upon iterations, an accurate model was obtained with 7, 86,000 points as shown in Fig. 6. This point cloud data was processed to generate a 3D solid model via a surface model as shown in Fig. 7 and Fig. 8. The fineness of the surface was such that even the most intricate curves and cracks on the skull could be captured effectively.

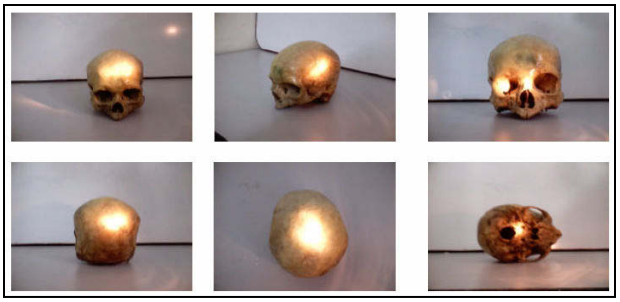

Fig: 4 Different views of the physical skull

The following design procedures from the point of refined and accurate scan model illustrate the alternate method in realizing the ergonomic design of the helmet:

(1) Reverse engineering of a skull (Fig. 6).
(2) Process the point cluster to generate a 3D solid model of the skull via a surface model (Figs. 7, 8)
(3) Reverse engineering of a helmet to produce a 3D model (Figs. 9, 10, 11).
(4) Super impose the skull and helmet at the center axis and align them (Figs. 12, 13).
(5) Perform Boolean operations to capture the outer surface of the skull as inner surface of the helmet (Fig. 14).
(6) Smoothen the interior surface of the helmet to achieve minimum manufacturing difficulty.

Make offset of the interior surface to provide a clearance for cushioning material to obtain the final model (Fig. 15)

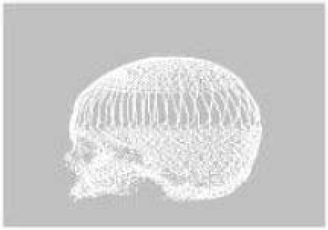

Fig 5: 10,000 Point cluster of a skull

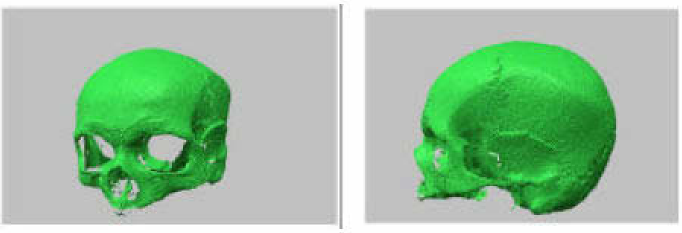

Fig 6 a,b: 7,86,000 Point cluster of a skull

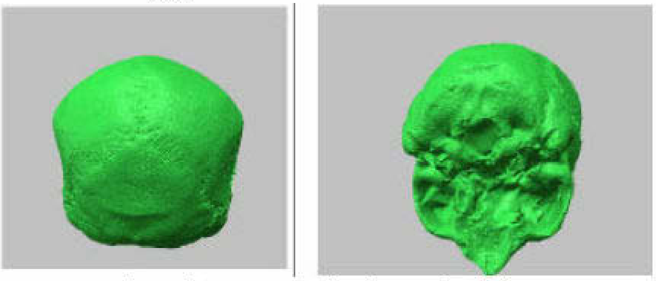

Fig 6 c,d: 7,86,000 Point cluster of a skull

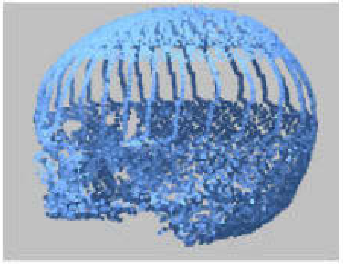

Fig 7: Polygon model

* No. of Vertices : 601542
* No. of Faces : 1198721
* Width of B.Box : 138.59139 mm
* Height of B.Box : 175.84673 mm
* Depth of B.Box : 146.25244 mm
* Center of Shell : 0.41924, 1.69691, 1.05115
* Center of Mass : 2.96670, -0.00949, 2.92926
* Area of Shell : 94597.17472 mm2
* Volume of Shell : -1.#IND0 mm3

Fig 8a,b: Surface model of a skull

Fig 9: Physical helmet

Fig 10: Helmet-point cluster

Fig 11: Helmet-surface model

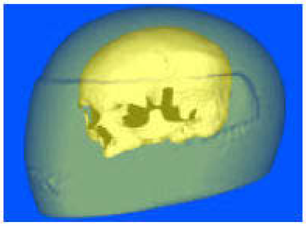

Fig 12: Superimposed model

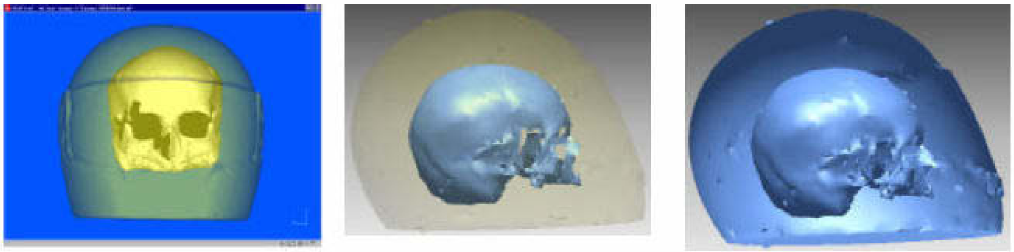

Fig 13: Superimposed model for alignment

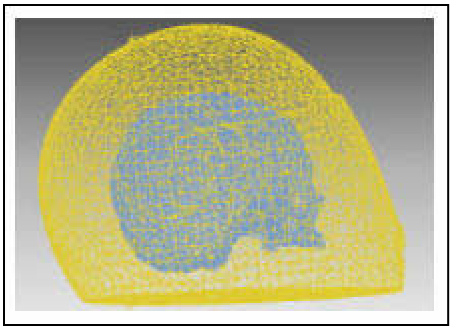

Fig: 14 (a) Performing Boolean Operations

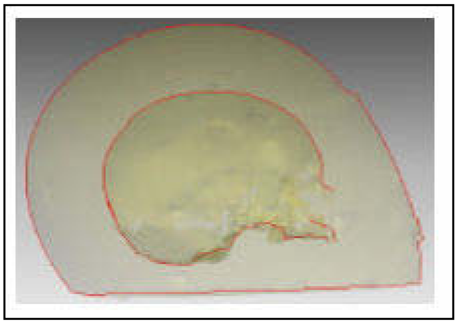

Fig: 14 (b) Performing Boolean Operations

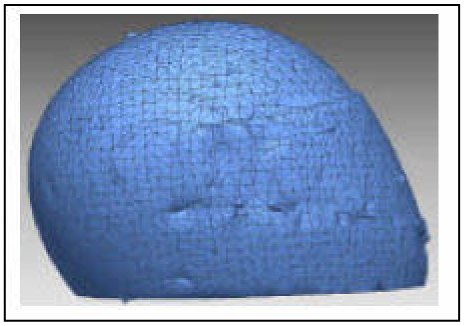

Fig: 15 Final Helmet Model

## 4. CONCLUSIONS

In the ergonomic design of a helmet using bio-modeling, it was attempted to achieve the fundamental functional requirements of maximizing energy absorption and good distribution of impact forces in the design of crash helmets. In this design approach, bio-modeling of a skull and helmet modeling were interfaced using a reverse engineering method to develop a cost-effective way to produce helmets with ergonomic fit to enhance safety and comport. Further, it is possible to design a helmet to fit to individual variations in shapes and sizes.

In the design methodology, it was observed that contact area of the helmet can be effectively maximized which improves the safety of the head as well as the comfort fit. In future, the final helmet model can be interpreted to identify the weaker sections of a helmet and integrated with lightweight, heavy strength materials to enhance the performance capability. Due to the cost limitations of the medical images and the software, the alternate design approach is attractive but more research work is needed to standardize the methodology to gain a commercial level. The realization of the conceptual model would lead to increasing technological applications of medical images at cheaper costs. Affordability of custom-made helmets would help growing awareness among the public about safety requirements in a host of application such as equestrian, motor sports, scooters, skating, skateboard, skydiving, sledding, snow sports, tricycles, etc.

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