Use of optimization to position dummies in crash simulations

A Chawla[1], Member
S. Mukherjee, Non-member
S.K. Iyer, Non-member

ABSTRACT

Positioning of a motorcyclist dummy model for carrying out car-motorcycle crash simulations has been a critical issue in understanding the kinematics of the motorcyclist. This paper outlines an approach to position a model of a human dummy used in motor cycle crash tests, the Motorcyclist Anthropometric Test Device (MATD) based on experimentally measured co-ordinates for car-motorcycle crash simulations. An optimization technique has been used which minimises an error function. The dummy points thus obtained are compared with the experimental positions recorded.

Keywords : Crash dummies, Motorcycle Anthropometric test device (MATD), Dummy Positioning, Optimization.

INTRODUCTION

The objective of this study was to develop a technique to position a human body dummy model by quantifying and minimising the error between the points in the dummy and the corresponding experimental positions. We have been doing car-motorcycle impact simulations and comparing simulation results with experimental data[1]. In these simulations a computational model is used in place of the Motorcyclist Anthropometric Test Device (MATD)[5] used in the experiments. Since the dummy consists of a set of jointed bodies, positioning the dummy so as to match the initial experimental positions is a difficult task. The problem becomes even more difficult because of the uncertainty in the experimental point for which position is normally recorded using coordinate measuring systems, and also because of a lack of correspondence between the measured points and a node in the FE model of the dummy. We have observed in the simulations that positioning of the dummy model significantly affects the simulation results[7]. While validated models of the car and motorcycle are easily available, errors due to wrong positioning of the dummy need to be minimized. This paper initiates an approach to position the MATD model on the motorcycle model.

[1] Address of Communicating Author:
A Chawla
Department of Mechanical Engineering
Indian Institute of Technology,
New Delhi 110016

METHODOLOGY

The problem involves the determination of the joint rotations, given the experimentally measured co-ordinates of the dummy with respect to the reference co-ordinate system. This is an inverse-kinematics problem. A lot of iterations were earlier required to position the dummy model since previously it was done by trial and error. Given the experimental co-ordinates of the dummy, the developed program now computes the necessary joint angles to put the specified body parts in the desired positions through required motions.

During experiments, joint locations are measured on the dummy parts and locations of these key points are noted. Some photographs of the dummy are also taken to guide in location of the points corresponding to the experimental points in the computer model. In the current study, a set of experimental points is assumed. The points located in the dummy model are shown in Figure 1. Thirteen points were taken in the dummy corresponding to the experimental points. These points are shown schematically in Figure 1. Some of the points were located on the basis of the photographs and others on the basis of length comparison between points. Specific nodes on the dummy are taken as the reference point and are matched with the corresponding experimental point. Since the experimental points do not have a correspondence with the nodal points, errors are likely. This makes the optimization difficult. In addition, the experimental points are often not very accurate as they are obtained by taking the tip of a coordinate measuring machine to the location to me measured. Being a manual process, a few millimetres of error can easily creep in.

One reference point near the pelvis is taken as a common reference point between the dummy and the model. The dummy model is translated to match the reference point on the pelvis / hip. Thus the final value of error at the hip point is always zero. The proper location of the hip point is critical considering the fact that it is the reference point. Any error in locating the hip point is likely to add the value of the final error at the other co-ordinates.

On the basis of the known experimental coordinates, a set of transformations are determined for the dummy parts so as to match the locations of all the parts. The complete body requires 1 translation and about 35 rotations about different joint axis to position the model close to the experimental position. Rotations are permitted only about the joint centres. The various joint centres in the dummy model are shown in Figure 2 (a). An error function based on these 35 angles is defined. This error function is then minimized to get the set of optimum parameters required to position the model.

First a translation is required to match the hip point with the corresponding experimental hip point. Figure 2(c) shows how the torsos are initially matched. The upper torso of the model is represented by the hip point (a_1), right shoulder point (a_2) and the left shoulder point (a_3). Similarly the upper torso of the experimental points is represented by the hip point (b_1), right shoulder point (b_2) and the left shoulder point (b_3) as shown in Figure 2(c).

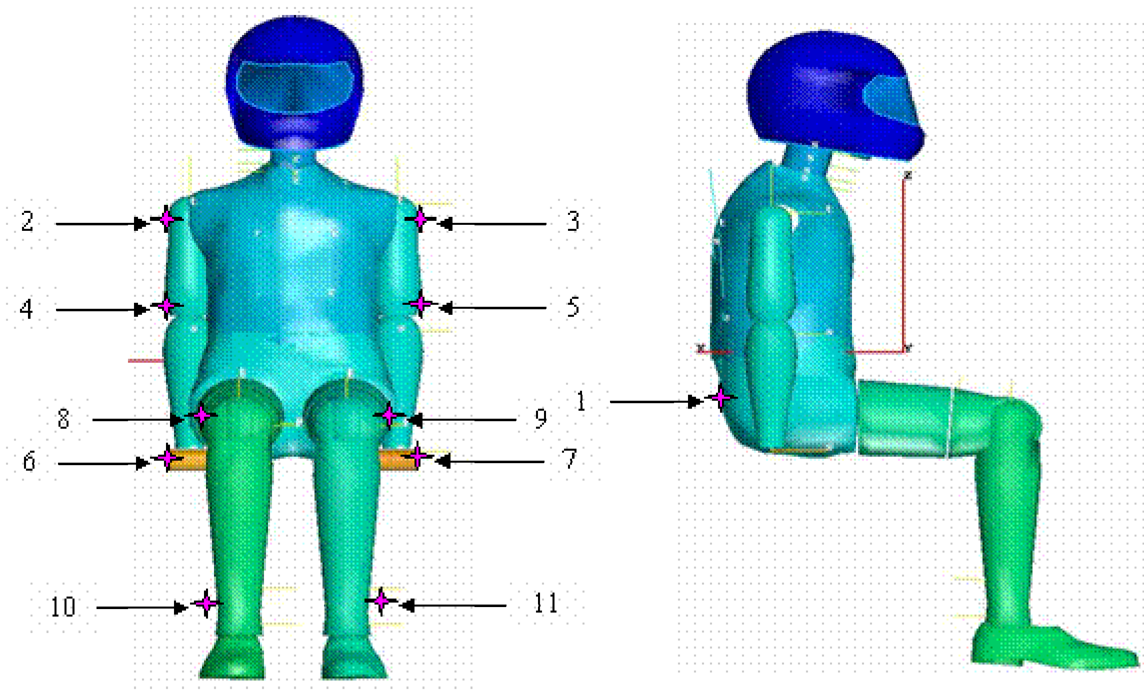
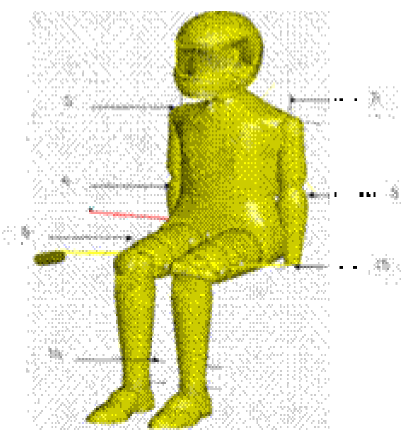
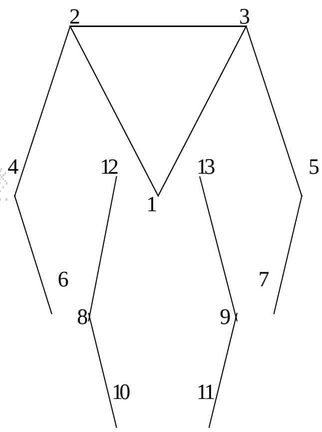


Figure 1 Points located in dummy model





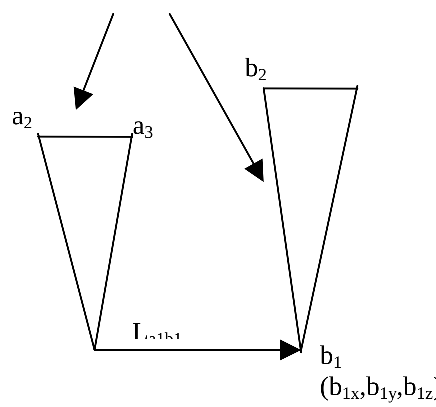


Figure 2(a) Joint center in the dummy model

Figure 2(b) Schematic representation of the points on the dummy

Figure 2(c): Translation of Hip point

Figure 2 The joint definitions, their schematic representation and translation to match the hip point

The translations required are given by $t_x=(b_{1x}-a_{1x})$, $t_y=(b_{1y}-a_{1y})$ and $t_z=(b_{1z}-a_{1z})$ and the translation matrix T is a standard transformation matrix given by

$$T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ t_x & t_y & t_z & 1 \end{bmatrix} \quad [1]$$

A set of reference points are thus defined on the dummy model as a_i's and the corresponding points on the dummy are called b_i. After the translation of the hip point the points a_1 and b_1 coincide (being the correspond points on the hip which are matched by the initial translation) making the final value of error at the hip point zero. On each joint a_i, three rotations in the local r, s and t directions are permitted. These local r, s, and t axis are defined by defining the points a_{1jr} and a_{1js} along the local r and s axis respectively. The local t axis is then obtained as the cross product of r and s axis. Once the axis is defined, rotations are provided about the joint centers. Inexact link lengths cause errors at the reference points. These errors at the reference point are then calculated and the error function is minimized.

Rotations that are allowed about a joint center are obtained from the moment rotation curves of each joint. From these moment curves it can be seen that each joint permits rotation about certain degrees of freedom only. These correspond to the natural degrees of freedom of the human body joint. Thus at each joint rotations are permitted only about certain degrees of freedom depending on the joint kinematics. The required angles of rotation and the axis of rotation are then obtained by minimizing an objective function subject to the lower and upper bounds of the rotation angles permitted about that joint.

The error function used for minimization is -

$$E = \sum_i ((a_{ix} - b_{ix})^2 + (a_{iy} - b_{iy})^2 + (a_{iz} - b_{iz})^2) \quad [2]$$

The above error function is the sum of the squares of the distance between the experimental co-ordinates and the corresponding points in the dummy model. This is the objective function that is minimized. It is an indirect function of the different joint rotations. The values of b_i^s does not change during the optimization process since they correspond to the experimentally measured points. After each transformation, the variables a_i^s change and the minimum error is obtained when there is not much appreciable change in the objective function between successive iterations. A tolerance level is specified and violation of this tolerance leads to the termination of the optimization algorithm.

The present optimization problem involves the minimization of the error function on which constraints are imposed. The permissible ranges of rotations allowed at that joint centre impose the constraints. There are about 35 rotations about various joint centres and each has range of permissible rotations about that axis.

MATLAB^{TM6} provides an optimization tool box that consists of number of optimization algorithms. To solve the present optimization problem 'fmincon' function was used. It is a deterministic calculus-based method. It seeks optima by hopping on the function and moving in a direction related to the local gradient. This is simply the notion of hill climbing: to find the best, approach in a steepest permissible direction. This function uses 'sequential quadratic programming' method to find the optimal solution. This method involves application of Newton's method to find the stationary point of the Lagrangian function[4]. Since the objective function depends on the parameters (joint rotations) in an indirect manner, other optimization methods were also tried. Another method which gave encouraging results was genetic algorithms (GAs) but the results from GAs are not being reported in this paper.

CASE STUDY RESULTS

The developed program has been run on a case study based on a set of experimentally measured data. Table 1 gives the set of initial experimental data points used as input. These x, y, z co-ordinates are fed to the MATLAB based optimization program as input. Table 2 shows the initial differences between the link lengths between the measured data and the initial position of the model. A set of transformations are then performed on the different dummy parts. These transformations are defined relative to the initial dummy position and are obtained from the optimization tool used.

To check the validity of the transformations, the transformations are then carried out on the Pamcrash™ [8] dummy model using the Pam-Generis™ pre-processor [8]. Table 3 gives the final co-ordinates achieved by performing the above set of transformations on the dummy model. These results obtained from the MATLAB program match exactly with the final points of the dummy obtained in PAM-GENERIS™ [8]

From the above results the error was calculated which is the distance between the final points achieved in the model to the corresponding experimental points. Table 3 gives the values of the error at the 11 dummy joint positions before and after the optimization. Figure 4 shows these errors diagrammatically. The first part of the figure shows the errors before the transformations, after the first translation and after the complete set of transformations obtained after optimization. The reduction in error is clearly seen.

As expected the error at the hip point is zero. This is because hip point is taken a reference point that does not undergo any transformations, except at the first step when it is translated and matched with the corresponding experimental position. As discussed earlier one factor that can possibly cause significant error at all points is the location of the hip point on the dummy model.

From Figure 4 the presence of large error of over 4 cm at the right and left shoulder can be seen. This behaviour is similar to the one indicated by the error plot for the previous data points. This is because of a difference in the link lengths 1-2 and 1-3 between the experimental dummy and the dummy model available.

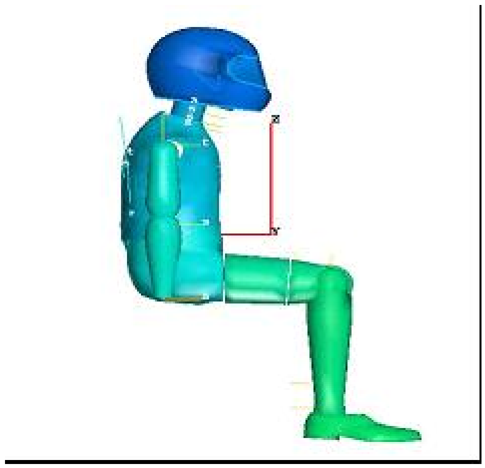


Figure 3 (a) side view before transformation

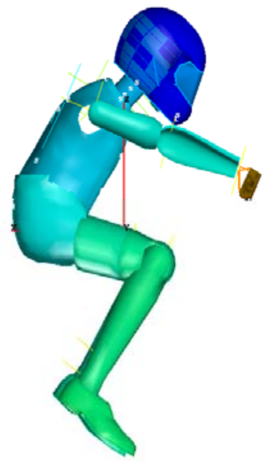


Figure 3 (b) side view after transformation

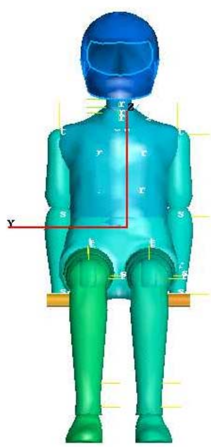


Figure 3 (c) front view before transformation

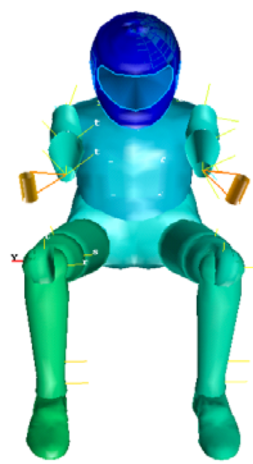


Figure 3 (d) front view after transformation

Figure 3 The side and front views of the dummy before and after transformations

CONCLUSIONS

A technique has been developed to position the dummy in the motorcycle based on experimentally measured co-ordinates. The code developed for positioning of the MATD model quantified the error and minimised it. A hill climbing based sequential quadratic programming technique has been used (Fletcher, 2000). The developed tool shows the suitability of optimization methods in this application and we can now expect that once the dummy model is positioned using this technique, better results of the car-motorcycle crash simulation will be obtained

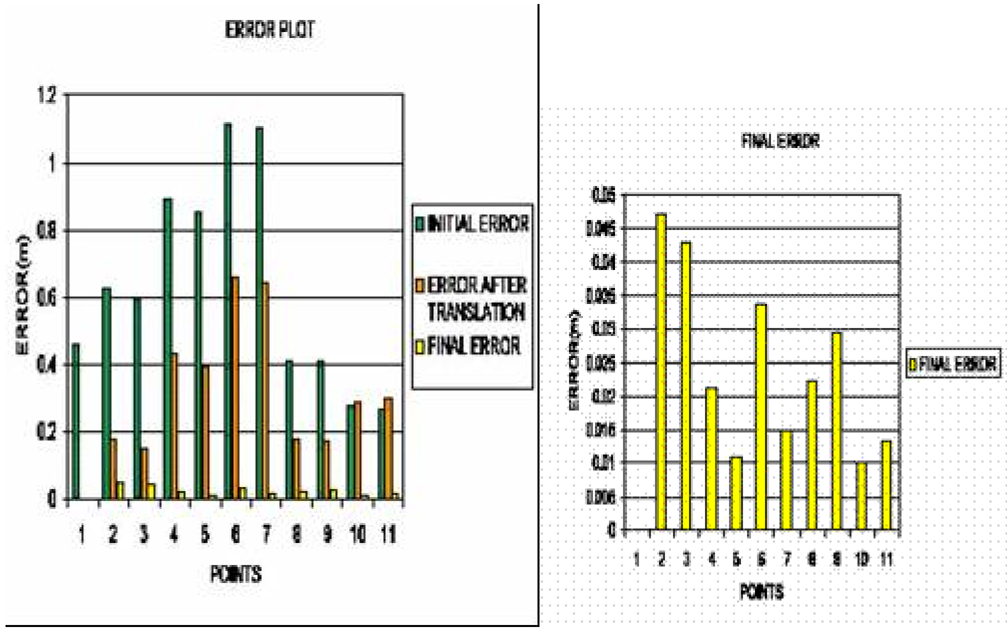


Figure 4 Initial and final error at various points

REFERENCES

1 Chawla A., Mukherjee S., Mohan D., Singh M. and Nakatani T., (2001) A Methodology for car-motorcycle crash simulations, Research Journal, Vol 23, No 2,pp 18-21

2 Chawla, A., et al., “FE Simulations of Motorcycle-Car Frontal Crashes, Validation and Observations,” 18^{th} ESV, 2003

3 Chawla A, Mukherjee S, Mohan D, Bose D, Rawat P, Nakatani T and Sakurai M, FE Simulations of motorcycle car frontal crashes, validations and observations, International Journal of Crashworthiness, 2004, Vol 10, No 4, pp 319-326.

4 Fletcher R., “Practical Methods of Optimization”, John Wiley and sons, Second Edition-2000

5 ISO13232, Motorcycles—Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles, ISO 13232, first edition 1996-12-15.

6 MATLAB®, Release 12.1, The MathWorks, Inc. USA.

7 Mukherjee, S., et al., “Motorcycle-Car Side Impact Simulation,” IRCOBI, 2001

8 PAM-CRASH™ range of software, ESI Group Software Product Co. Paris, 2000.

S.No	Measured Point	X-AXIS(mm)	Y-AXIS(mm)	Z-AXIS(mm)
1	Right pivot	484.9	150.3	351.4
2	Right step centre	462.1	277.4	313.6
3	Right dummy ankle	452.7	287.8	419.5
4	Right dummy knee	682.5	299.1	723.1
5	Right dummy shoulder	467.3	199.5	1253.8
6	Right helmet centre	606.5	141.6	1510.6
7	Right dummy elbow	683.1	224.8	1105.8
8	Right handle centre	982.6	305.9	966
9	Right back mirror	1368.5	357.4	973.7
10	Ground point	1629	-50	19.1
11	Left rear wheel axis	0	-129.5	290
12	Left pivot	484.6	-135.8	350.3
13	Left step centre	449.2	-252	315.5
14	Left dummy ankle	431.5	-246.4	426.1
15	Left dummy knee	662.4	-269.4	722.8
16	Dummy hip point	219.8	13.9	764.2
17	left dummy shoulder	443.8	-178.4	1252.9
18	left helmet centre	594.2	-111.9	1513.8
19	left dummy elbow	655.3	-204	1101.7
20	left handle centre	967.4	-260.8	970.8
21	Headlamp centre	1427.4	-1.4	826.8
22	Left front wheel axis	1418.3	-135.4	290
23	Left back mirror	1346	-350.7	1000
24	Handle centre	1029.4	0	915.7
25	Helmet neck part	675	7.7	1329.1
26	Tail lump centre	-213.8	19.4	878.3

Table 1 Experimentally measured co-ordinates of the reference points on the dummy

Experimental link-Length (m)	Initial link length in the model (m)	Final Length-(Theoretical) (m)
L_{b1b2} = 0.5791	L_{a1a2} = 0.5485	L_{a1a2} = 0.5363
L_{b2b3} = 0.3786	L_{a2a3} = 0.3828	L_{a2a3} = 0.3804
L_{b1b3} = 0.5709	L_{a1a3} = 0.5450	$La1_{a3}$ = 0.5367
L_{b2b4} = 0.2629	L_{a2a4} = 0.2436	L_{a2a4} = 0.2436
L_{b3b5} = 0.2612	L_{a3a5} = 0.2437	L_{a3a5} = 0.2437
L_{b4b6} = 0.3403	L_{a4a14} = 0.3073	L_{a4a14} = 0.3191
L_{b5b7} = 0.3432	L_{a5a15} = 0.3028	L_{a5a15} = 0.3194
L_{b1b8} = 0.5451	L_{a1a8} = 0.5358	L_{a1a8} = 0.5587
L_{b1b9} = 0.5271	L_{a1a9} = 0.5237	L_{a1a9} = 0.5444
L_{b8b10} = 0.3809	L_{a8a10} = 0.4076	L_{a8a10} = 0.4076
L_{b9b11} = 0.3767	L_{a9a11} = 0.4088	L_{a9a11} = 0.4088

Table 2 Initial differences in link lengths

Points	Experimental Co-ordinates b (m)	Initial Co-ordinates (m)	Coordinates after translation (m)	Final Co-ordinates (m)
a_{1x}	-0.2198	0.21548	-0.2198	-0.2198
a_{1y}	0.0139	0.0191	0.0139	0.0139
a_{1z}	0.7642	0.61495	0.7642	0.7642
a_{2x}	-0.4673	0.140804	-0.2945	-0.4498
a_{2y}	0.1995	0.2161	0.2109	0.203
a_{2z}	1.2538	1.1214	1.2707	1.2103
a_{3x}	-0.4438	0.138193	-0.2971	-0.449
a_{3y}	-0.1784	-0.1667	-0.1719	-0.1774
a_{3z}	1.2529	1.1214	1.2707	1.2102
a_{4x}	-0.6831	0.17916	-0.2561	-0.665
a_{4y}	0.2248	0.2372	0.232	0.2345
a_{4z}	1.1058	0.8818	1.0311	1.1006
a_{5x}	-0.6553	0.16577	-0.2695	-0.6659
a_{5y}	-0.204	-0.2017	-0.2069	-0.2062
a_{5z}	1.1017	0.8818	1.0311	1.1029
a_{6x}	-0.9826	0.06329	-0.372	-0.9545
a_{6y}	0.3059	0.2049	0.1997	0.2962
a_{6z}	0.966	0.59901	0.7483	0.9816
a_{7x}	-0.9674	0.06329	-0.372	-0.9532
a_{7y}	-0.2608	-0.1667	-0.1719	-0.262
a_{7z}	0.9708	0.59901	0.7483	0.975
a_{8x}	-0.6825	-0.2963	-0.7316	-0.6937
a_{8y}	0.2991	0.1677	0.1625	0.3089
a_{8z}	0.7231	0.67011	0.8194	0.7396
a_{9x}	-0.6624	-0.2818	-0.7171	-0.6748
a_{9y}	-0.2694	-0.135	-0.1402	-0.2844
a_{9z}	0.7228	0.67189	0.8211	0.7448
a_{10x}	-0.4527	-0.2661	-0.7014	-0.4496
a_{10y}	0.2878	0.1536	0.1484	0.2797
a_{10z}	0.4195	0.2639	0.4132	0.4144
a_{11x}	-0.4315	-0.2661	-0.7014	-0.43
a_{11y}	-0.2464	-0.1154	-0.1206	-0.2341
a_{11z}	0.4261	0.2639	0.4132	0.4214

Table 3 Results of co-ordinate transformations

Points	Initial error (m)	Error after translation of hip point (m)	Final error (m)
1	0.4602	0.0000	0.0000
2	0.6226	0.1740	0.0470
3P	0.5968	0.1479	0.0430
4	0.8910	0.4335	0.0212
5	0.8500	0.3922	0.0109
6	1.1130	0.6569	0.0336
7	1.0997	0.6418	0.0149
8	0.4114	0.1742	0.0222
9	0.4068	0.1713	0.0294
10	0.2776	0.2852	0.0101
11	0.2661	0.2981	0.0133

Table 4 Errors in dummy points before and after optimization

LIST OF FIGURE CAPTIONS

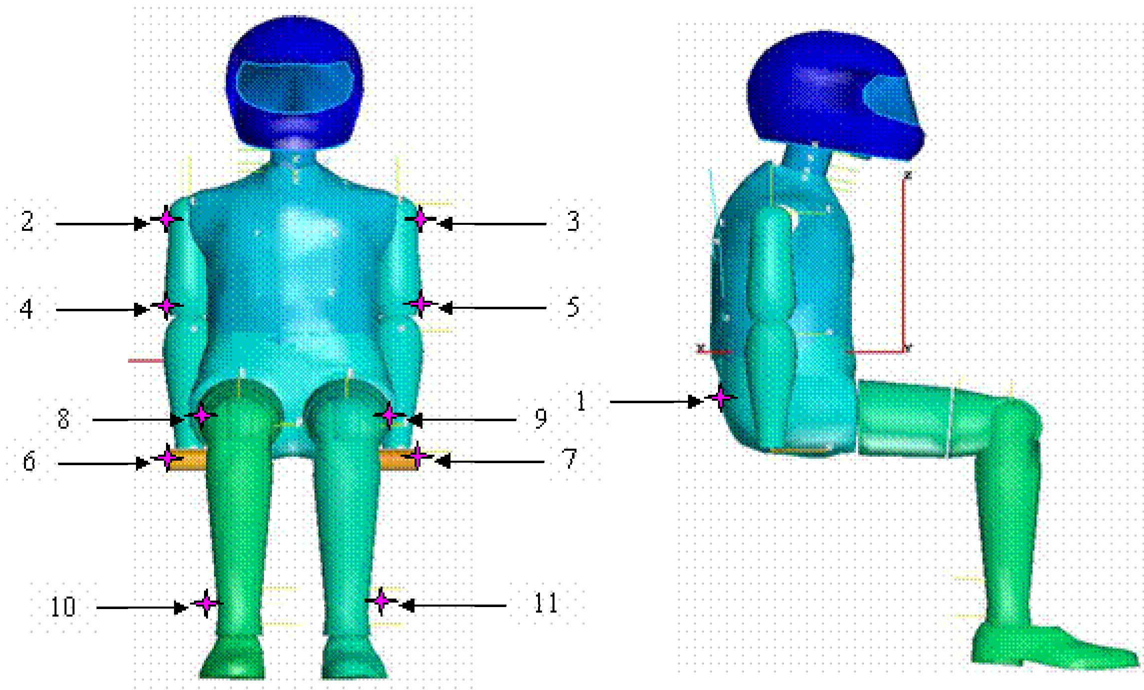


Figure 1

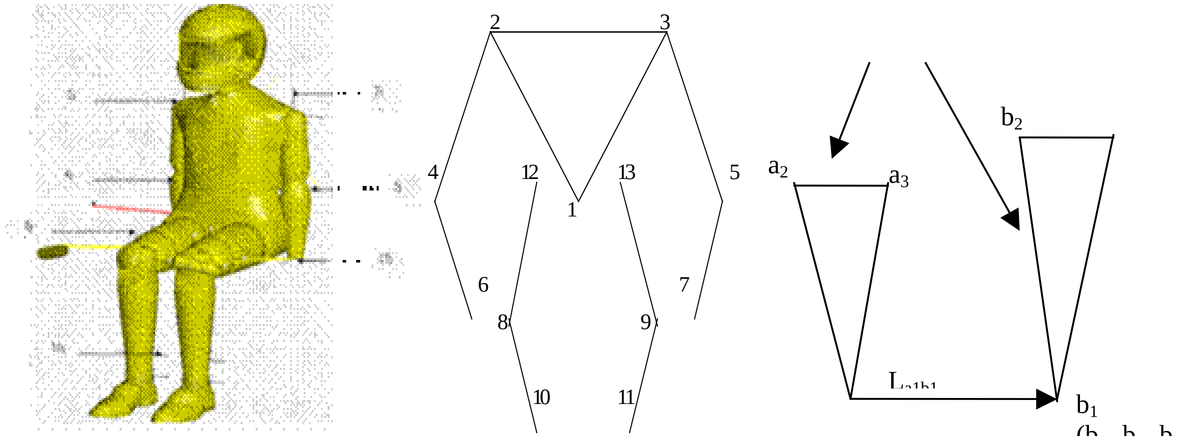


Figure 2

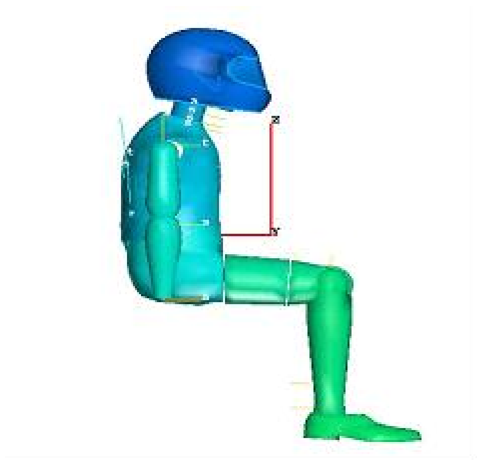


Figure 3 (a)

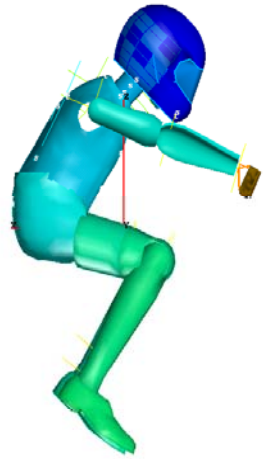


Figure 3 (b)

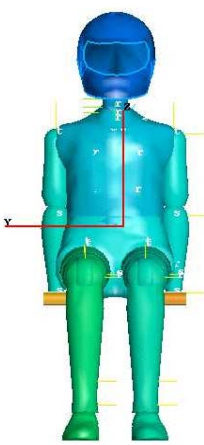


Figure 3 (c)

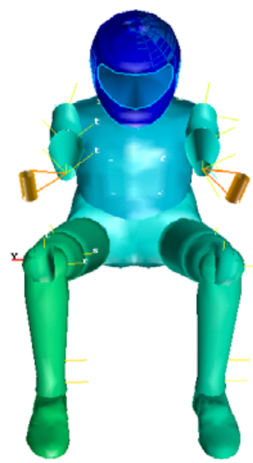


Figure 3(d)

Figure 3

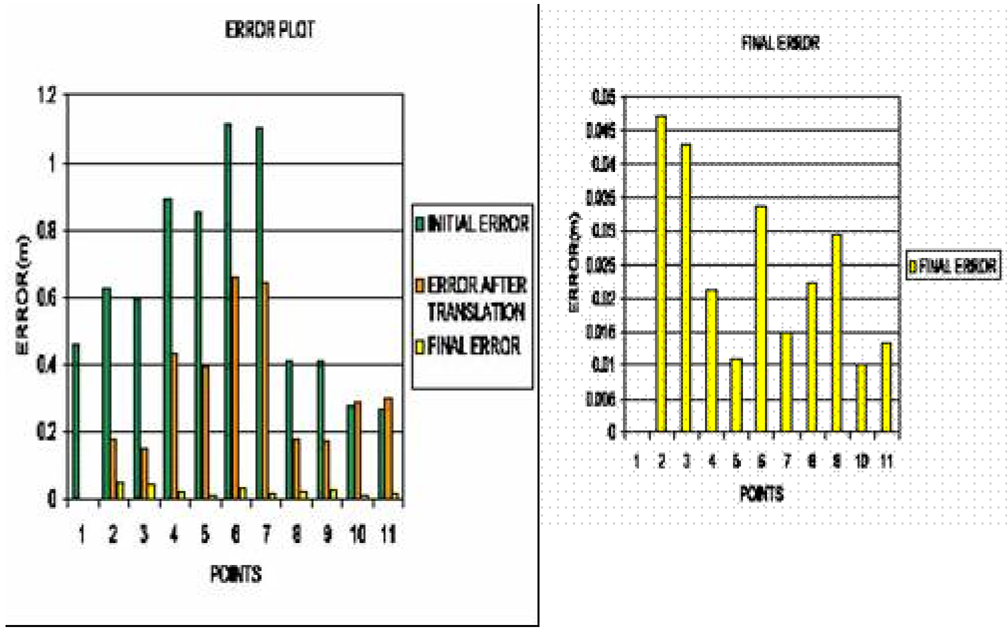

ERROR PLOT
1.2
1
0.8
0.6
0.4
0.2
0
ERROR(m)
1 2 3 4 5 6 7 8 9 10 11
POINTS
INITIAL ERROR
ERROR AFTER TRANSLATION
FINAL ERROR
FINAL ERROR
ERROR(m)
1 2 3 4 5 6 7 8 9 10 11
POINTS
FINAL ERROR

Figure 4