Dynamic analysis on the whole body with sitting posture for impact loading

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Abstract: Objected to influences of impact to the whole body with sitting posture, the inverse dynamical analysis is carried out. Firstly by using the high-speed video camera, the images of the marked points on the body and the impact platform are captured and then the marked points’ displacement can be obtained. Taking those displacements as input parameters, the inverse dynamical composition are continued with AnyBody Modeling System and responses are obtained and the impact transfer performance of the vertical direction in the human body with sitting posture and the muscle activities could be confirmed. From the sitting musculoskeletal model, it is concluded that acting forces of the joints and the mechanism performance of those parts of the body could be computed with different impact loadings, which would be conducive to understand the impact influence for the most parts of the body; especially for those parts that could be not tested. The study could be better for the reasonable countermeasures with certain postures for random impacting loadings.

1 Introduction

The dynamic research of the human body, as a key point of the biomechanics, is now getting more and more attention. It could be used to evaluate the comfort of the mobile members, analysis of human body tolerance under special conditions, the study of the countermeasures for the impact conditions etc.

As a complex multi-body system, the whole body is not only different in the mechanical properties of each part of the subject but also at the same time is different in mechanical properties in individuals. In order to obtain the dynamic responses of the human body, a variety of dynamic models are established, including the centralised parameter model, the finite element model, the multi-body model, the skeletal muscle model etc. Zhang et al. [1–3] used the equal weight genetic algorithms to the four degree of freedom series linear model for simulation analysis of man–vehicle system. Abbas et al. [4, 5] used the weighted genetic algorithm to optimise the parameters of the four degree of freedom mixed linear model, which is used to guide the design of vehicle suspension. Wu [6] carried out the dynamics analysis with four degree of freedom hybrid linear model for the passenger with sitting posture on the railroad car or the train. Zhang et al. [7] used the six degree of freedom bidirectional model to carry out the parameter identification. Liu et al. [8] applied the six degree of freedom linear model to analyse the vibration characters under sitting posture. Harsha et al. [9] used the nine degree of freedom bidirectional linear model to discuss the dynamic response of human body in two cases which are with and without seat backrest. Liu [10] used the twelve degree of freedom linear three direction model and applied it to vehicle handling and stability simulation. Zhang et al. [11] used the twenty-three degree of freedom linear bilateral dynamic model for the vehicle simulation by using ADAMS.

As for further study, some muscle skeletal dynamics models were set up to study skeletal parts dynamic response and muscle activities by using forward and inverse dynamic methods. The displacements of the key parts and external forces obtained in the experiments were used as the input and according to the dynamic model the dynamic responses and the muscle activities were obtained. The forces of each joint were obtained from the dynamic model, which were very close to the actual data. The current software systems included are AnyBody Modeling System, ADAMS life Mod, OpenSim etc. With the AnyBody Modeling System, the muscle skeletal model was used for learning the relationship between the muscle activities, forces and the conditions such as riding speed, external loading, so on [12]. Also the research about the optimisation of the work tasks and workplace layouts for the subjects is carried out by using the muscle skeletal model [13].

With the ADAMS, according to the quality distribution of the outer space suit, the dynamic model including the suit and the subject were set up for analysis on the joint’s forces and other dynamic responses, which were used for astronaut training guidance [14].

From the references, it could be concluded that theoretical research and its application about human body kinematics and dynamics by using mechanics, biomechanics and life science are getting more and more concerned, which could be providing theoretical basis for experiments and for special counter-training guidance. In the current research, based on inverse dynamics fundamentals, the muscle skeletal dynamic model is set up for dynamic characteristics of the parts of the whole body and the muscle activities with sitting postures during the impact processing.

2 Methods

Here, we used AnyBody Modeling System to set up a body musculoskeletal model under sitting posture with impact loading to obtain the responses of different parts of the body. During the process, the certain points’ acceleration would be used to verify the results from the model and then the influences of the impact loading for the body would be discussed.

2.1 Sitting posture musculoskeletal model in AnyBody Modeling System

The sitting posture musculoskeletal model is built using the AnyBody Modeling System, which is a software for development and analysis of multi-body dynamics models, particularly models of the musculoskeletal system. The model is defined in a text-based, declarative, object-oriented language called AnyScript. The model consists of segments, joints between joints and muscle-tendon units with physiological properties. While the loading is added to the model, the movement is carried out, from which the
information, properties such as tendon elastic energy, metabolism, muscle activation and antagonistic muscle actions are derived. With the AnyBody Modeling System, it could employ inverse–inverse dynamics for optimisation of the movements. In the current research, the whole body musculoskeletal model shown in Fig. 1 is revised from the standard standing model in the system.

The Hill-type muscle model is used as shown in Fig. 2 [15]. The magnitude of the muscle force depends on the activities and the force generation properties are determined by length and velocity of the force fibre. The tendon is attached to the muscle and completes the musculotendon unit. The $F_{MT}$ is the muscle force, the $l_M$ is the muscle fibre length, $l_{MT}$ is the musculotendon unit length, CE is the contractile element and PE is the passive element.

2.2 Structural parameters determination of the subject

According to national standard GB/T5703-1999, the subject is with height of 173 cm and weight of 70 kg. The structural parameters of the segments such as the mass, length etc. are measured. The measurement processes are based on national standard GB3975-83 and GB5703-85. The subject is in sitting posture, with parallel legs, knees into right angle, flat feet on the ground and hands on the thighs. Then parameters of the upper arm, forearm, thigh, shin etc. are obtained (Table 1).

2.3 Kinematic data acquirements

In the current research, the kinematic data used for the model are obtained by using high-speed video cameras for the lateral direction and the anterior–posterior direction. The key points marked on the body include lateral malleolus, lateral femoral condyle, anterior superior iliac spine, acromion, temple etc. Also the impact platform and the seat of the subjects are marked. The total marked key points are totally 13. The marked points are shown in Fig. 3. The points of number 1, 3, 5, 7, 9, 11 are on the left side, which are marked on the temple of the head, the shoulder, the femur lateral condyle, the lateral malleolus, the calcaneus, respectively. The points of number 2, 4, 6, 8, 10, 12 are on the right side. The point 13 is marked on the platform. In the process of the impacting with sitting posture, the chair is bounded on the platform with the same impacting acceleration values. The subject is asked to leave the foot on the platform and maintain the natural balance of the body through the swing during the course, so the displacements of point 7, 9 and 11 could be considered same with the platform and the left side's movement is similar with the left side.

| Content       | Values, cm | Content          | Values (Unit) |
|---------------|------------|------------------|---------------|
| height        | 173.00     | weight           | 70.00 kg      |
| head height   | 18.00      | upper arm length | 27.90 cm      |
| forearm length| 24.00      | thigh length     | 45 cm         |
| shank length  | 48.50      | foot length      | 26 cm         |
| pelvis width  | 17.5       | trunk height     | 54 cm         |
| hand breadth  | 9.30       | hand length      | 18.20 cm      |

2.4 Comparison of acceleration data acquirements

During the course of displacements of the marked points on the subject, the acceleration of some points was captured. The points include on the head, on the knee and on the platform, which were marked with blue squares for point I, II and III, shown in Fig. 3. Those acceleration data were used to verify the reliability of the computed results from the model in the AnyBody Modeling System. For example, the experimental data of point III marked on the platform could be compared with the marked point 13 for the determination of consistence of the impact loading.

2.5 Process

In the current research, based on inverse dynamics fundamentals, the muscle skeletal dynamic model for dynamic characteristics of the parts of the whole body and the muscle activities with sitting postures during the impact processing are shown in Fig. 5.

3 Results

By using the model for the whole body with sitting posture under the impact loading, the computation could be carried out and the results would be used for the following: the comparison between the theoretical results and the experimental acceleration data, the joints’ movement analysis and the analysis about the whole body.

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response during the impact loading process. According to the peak value and the time interval of the main wave peaks for the theoretical results and the experimental data, the comparison could be done for the first impact process of the vertical direction. Continuously, the joints’ movement analysis is used to show the peak value and the time of occurrence. Then transmission and transfer ratio are considered for the impact for the whole body with sitting posture. In the current study, the analysis data about the platform, the skull and muscle activities are shown in the following sections.

3.1 Comparison between the theoretical results and the experiments

The acceleration curves of the platform and the computed results from the model were obtained as shown in Fig. 6. It could be seen that those curves change with similar trend. During the whole process, the first and main impact peak processes are very similar. At the same time, the difference between the impact peak values is about 10.3%. Also, the results from the computed results could show more information.

3.2 Analysis data about the skull part

The contrast of skull acceleration curves showed that the axial acceleration intensity curves are consistent. The difference is mainly caused by the pitching movement with the head. The accelerometer used in the experiment is a kind of high frequency sensor, which is hard to show a relatively slow change of position (Fig. 7). Also in the later period, the total acceleration intensity of the skull would continue to vary drastically and at the same time the axial rotation acceleration changed continuously. By using the model, it could be concluded that the vertical motion of the head and the head pitching motion converts each other in the later stage of the impact, and there will be a larger acceleration in the late impact.

It could be concluded that in the whole impact process, the maximum acceleration of the head is caused by the impact process,
and the rotation of the head and the linear motion are converted. The difference of the maximum value of impact is 21%.

3.3 Muscle activities analysis data

Through the model, it could be found that the muscular activation of the waist is the greatest in the process of impact with sitting posture, and the muscle activity of the right thoracic vertebra about T12 is shown in Fig. 8. During the impact process, the lumbar muscle group was most activated and gradually decays. The muscle activity of the right thoracic vertebra about L5 is shown in Fig. 9. Compared with the L5, the activity of the muscle group is lower than that of the T12 on both sides.

4 Conclusion

In the current research, the musculoskeletal model under sitting posture with impact loading in AnyBody Modeling System was set up. During the course, the displacements and acceleration were captured in the experiments. The displacements of the marked points were used to drive the model for inverse-inverse dynamical method. The acceleration was used to verify the displacements data reliability. The impacting transmission and the influences analysis were carried out.

According to comparison analysis, in the process the first, second and the third peak values of each part are smaller, the peak values are with smaller delay and acceleration error. Also some larger difference in some parts was likely to be revolving, which is caused by the superposition of the motion and the linear motion.

According to the motion transmission analysis, the shock responses from the seat to the head shows that the impact acceleration will become larger and the increase is about 8%, which showed that there was a certain overshoot phenomenon in the body under the impact environment.

In the later stage, the head rotation movement will be superimposed to the vertical movement, and the head shows a number of pitching movements which leads to increase in acceleration. The maximum acceleration is about 1.5 times the impact acceleration, which showed that with the condition the lack of head and neck immobilisation could result in an increase in head mobility and a similar ‘whipping’ pattern, which leads to contusion.

In short, the model using AnyBody Modeling System could be used to do the dynamic analysis on the whole body with sitting posture for impact loading. It’s outputs such as muscle activation, joint reaction forces and joint moments could provide useful information for an ergonomist. However, additional work is required to investigate further the difference of influence with different impact accelerations. Subsequently, the module could be used to improve the usability in proactive ergonomics.

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6 References

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