Simulation of Pushing the Push-Pull Rod Action Based on Human Body Dynamics

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Abstract. Using the software Anybody Modeling System，a human static-standing musculoskeletal model based on inverse dynamics is presented. According to the environmental constraints of cockpit, the human body model is defined, especially the selection and design of the input parameters on muscles, bones, joints, drive, and other aspects. From the model, the design simulates the flight operations of the pilot during the plane is approaching and landing, especially the right arm pushing the push-pull rod. According to the principle of inverse dynamics, the muscle forces on the right arm will be researched to elect larger ones. And the paper focuses on muscle parametric analysis and design. On the basis of muscle metabolism which is the parameter to evaluate the muscle fatigue, the design is optimized to find where the least muscle fatigue is. Results show that metabolism can provide an experimental basis for the design layout of the cockpit instruments, operating device.

Keywords: human factors, human body dynamics, numerical simulation, AnyBody optimal design.

1 Introduction

In the field of aviation, system failure caused by human error accounted for about 70% to 90%.With the improvement of hardware, human mistakes is playing a more and more important role in the influence of system failure. With the increasing demand for the safety of the flight stability, so in the aircraft design especially the design of the cockpit, the person-centered concept is also gradually accepted. Human Reliability Analysis (HRA) [1] is the development of the Human engineering which has gradually came into being a relatively independent discipline. HRA is based on analysis, forecast, decrease and prevention of human mistakes as core research, one of the reliability of the qualitative and quantitative analysis and evaluation, so it is important for human error probability reduces to the minimum of system that can accept. And because the cockpit which is of the main places the pilot work in: the main man-environment interaction process occurs in the cockpit. Therefore, the analysis of human factors has become an important part of the plane design process.

With the development of computer technology, digital technology has become more and more extensively applied in the digital prototype stage. The simulation and

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evaluation of the cockpit by establishing digital model of the human body for human factors gradually becomes a necessary method at home and abroad. The human body dynamics research is receiving more and more attention, on the one hand, it involves with human anatomy, human body metrology, biomechanics, robotics, and other disciplines, which is a newly emerged cross edge discipline. On the other hand, it has important research value and broad application, such as man-machine system analysis and the man-machine interface design. Because of the complexity of the pilot's human body structure, the diversity of human body action, the biological limitation and measuring instrument limitations, some parameters or index can't be measured. [2] So establishing a human body simulation model similar with a real human body system combining with related experiments and using the computer simulation technology is quite necessary to reveal and research the pilot in the mission of the characteristics and laws.

AnyBody Modeling System (AnyBody Technology Inc., Aalborg, Denmark)is a software based on inverse dynamics for the development and analysis of multi-body models, particularly those of musculoskeletal type. The system has its own language. AnyScript, which is of object-oriented type and models thus compiled can be defined in text format. Elements of the model, such as segments, joints, muscles, forces and so on, are declared in AnyScript, and grouped into different classes. Based on those classes and mathematical algorithms, muscle forces, joint reaction forces or other parameters can be obtained.

2 Parametric Modeling of Pull-Push Rod

The muscles, bones, joints, drive, environmental conditions, and other data need to be put in first in the modeling process, while muscle, bone, joint information already existed. [3] Drive and boundary conditions are required to be custom, such as importing motion capture locus data by the AnyBody solver (inverse dynamics) to obtain the results of muscles and joints, movement, function, etc. [4]

2.1 Modeling Using AnyBody Modeling System

The AnyBody modeling approach is as follows: [5]

1. Based on the established cockpit model, the three-dimensional geometry of the virtual environment must be in accord with the real ones. This results from the actual needs of the engineering problems, not brings the full range of virtual reality and really world-realistic visual experience. Importing stl file into AnyBody simulation software based on CAD, the simulation model of cockpit can be got.
2. In order to make the human body model more similar with the reality, some elements must be added. Body segments come first, which are rigid body elements and moves as the model runs. Body segments usually refer to body bone structure in the human modeling. Joints are regarded as the provider of the degrees of freedom in AnyBody Modeling System, compared with the rigid structure.
3. The next step is to define the movement. Elements at the push-pull rod fixed in this model, especially in the right arm, wrist, shoulder fixed in the seat, the elbow is the

main control movement. Elbow and wrist has remained in the same vertical plane and the body parallel to the axis.

4. Defining muscles is generally got through by some pre-defined point to reach the end; the process through the points can be defined depending on the size and length of the muscle. If the muscle is complex, some appropriate points need adding from the start to end points.
5. The final step is adding real geometry, while what obtained earlier is only the so-called stick-like shape. This is a straightforward way to view the model, which vividly reflecting the mechanical structure of the model, but does not look like a real physical body. Next the bones and other geometric model need to be added, including the bones of the 3-D graphics files.

At last, the three-dimensional musculoskeletal model of the whole biological body was developed using AnyBody Modeling System. (Fig. 1)

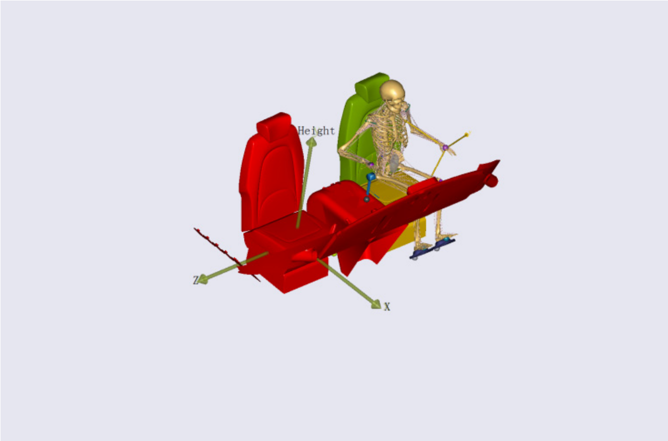

Fig. 1. Three-dimensional musculoskeletal model

2.2 Summary of Muscle Forces

During the operation, right hand fixed on the operating rod and right arm shoulder fixed on the seat, the pilot pushes pull-push rod. 190 muscle lines simulate right arm muscles in the AnyBody Modeling System (Fig. 2).

Fig. 2 shows that the muscle whose force is large in the process of the pushing rod is minority. To get more obvious results, larger muscle force should be elected to focus on. The muscles whose force are larger than 10N are biceps muscle, scapular deltoid, subscapularis, brachialis, brachioradialis muscle, latissimusdorsi, rhomboid muscle, teres major, left triceps, supinator, pronatorteres,musculus extensor carpi radialislongus.

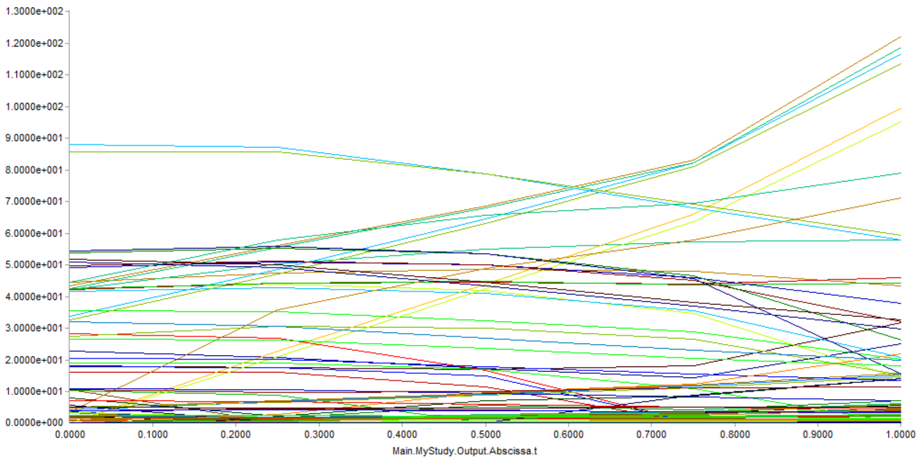

Fig. 2. Right arm muscle force simulation

2.3 Factors Selected of Muscle Force Comparison

This design focuses on where the pull-push rod locates. In a small area, the appropriate muscle force is selected as the main object of study as pull-push rod's location changes. [6]

The center of gravity of cockpit seat is centered as the origin, while the height rod layout is named as Height, the longitudinal position of rod layout is named as posX, the around position of rod is named as posZ. The position of rod initial position is Height = 0.29m posX = 0.15m, posZ =-0.6m.Every two quantities fixed, if the location of the push-pull rod changes, respectively as the initial position, the distance-increased position, the distance-reduced position ,there are three groups. Removing the same parts, a total of seven groups is shown in the following table:

Table 1. Comparison of muscle force factors conditions (unit: m)

Case number	Height	posX	posZ
1	0.29	0.15	-0.6
2	0.24	0.15	-0.6
3	0.34	0.15	-0.6
4	0.34	0.1	-0.6
5	0.34	0.2	-0.6
6	0.34	0.2	-0.625
7	0.34	0.2	-0.575

Based on the above table, Height for the impact of each block muscle can be compared by Case1, 2, 3, posX for the impact of each block muscle can be compared by Case3, 4, 5 and posZ for the impact of each block muscle can be compared by Case 5, 6, 7.

Many fibers make up a muscle bundle. Many bundles constitute a whole muscle. So analyzing the data will be completed by maximum muscle force statistical analysis (Fig. 3) and sum of muscle force statistics analysis (Fig.4).

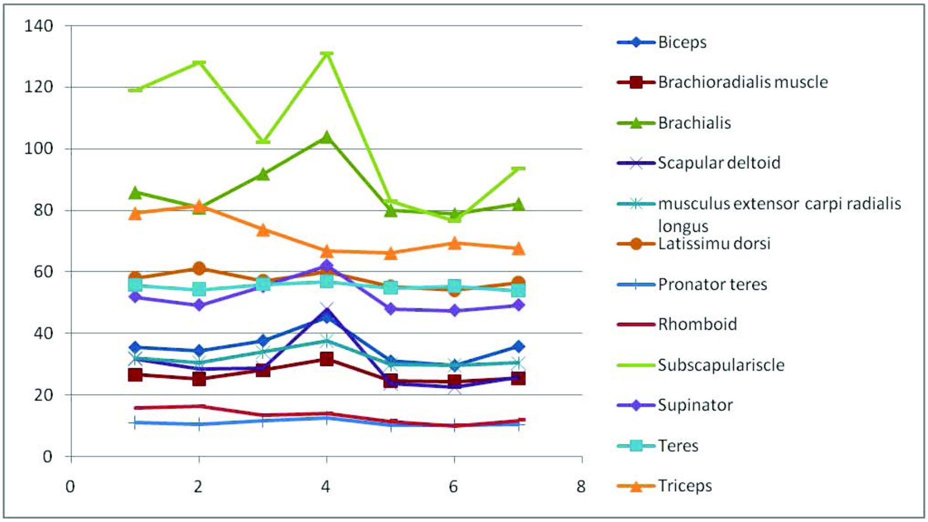

Fig. 3. Maximum muscle force statistical analysis (unit: N)

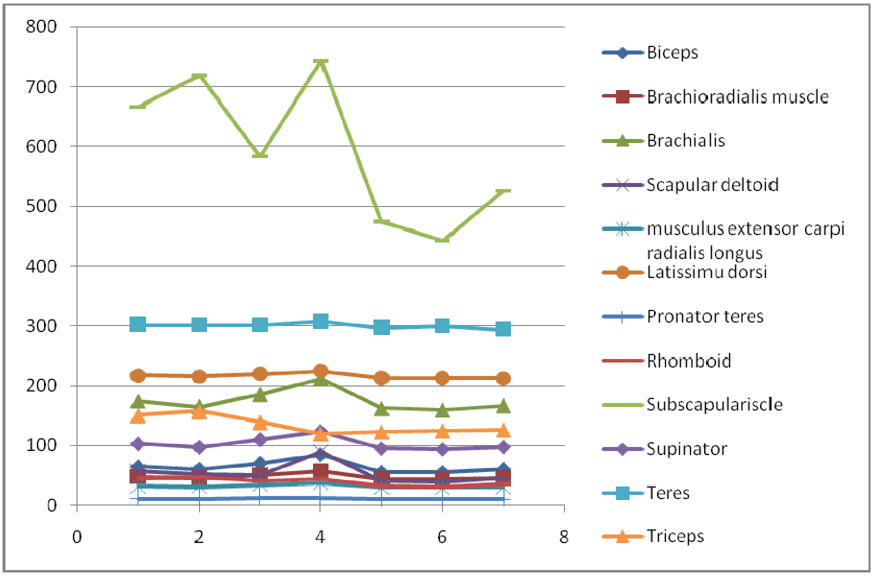

Fig. 4. Sum of muscle force statistics analysis (unit: N)

The results of two statistical analyses showed the subscapularis muscle, brachialis, triceps, humerus supination muscles, scapular deltoid, biceps change a lot as the location of push-pull rod changes, so the six muscles are selected as the main ones to research where the best location is. [7]

3 Optimal Design of Pull-Push Rod

The fatigue of muscle is evaluated by muscle metabolism. [8] The generation and consumption of human energy is defined to be metabolic energy which is reflected by the body's oxygen consumption. And the energy consumption of the body's metabolism per unit of time is called metabolic energy consumption rate. The fatigue intensity of the human body in the working process is shown by the body's energy consumption, oxygen consumption, heart rate, perspiration rate or relative metabolic rate as an index for judging, in addition, the human body need to consume a certain amount of energy in the static case, known as posture metabolic energy consumption. [9] When the pilot is operating the push-pull rod, we believe that the body's metabolic energy consumption can accordingly be divided into action metabolic energy consumption and posture metabolic energy consumption. The calculation of action metabolic energy consumption requires the action parameters of operation simulation process while the calculation of posture metabolic energy consumption requires the duration of the human body posture simulation process.

3.1 Parameter of Optimal Design

Therefore, the push-pull rod operator fatigue studies are established by the following parameters: [10]

1. height rod layout is named as Height, Height=0.24,0.29,0.34
2. the longitudinal position of rod layout is named as posX, posX=0.1,0.15,0.2
3. the around position of rod is named as posZ, posZ=-0.575,-0.6,-0.625
4. Evaluation:

Total muscle metabolic energy (Metablism_all)
Biceps metabolic energy (Met_bicep_brachii)
The brachialis metabolic energy (Met_brachialis)
Scapular deltoid metabolic energy (Met_deltoideus)
Subscapularis metabolic energy (Met_subscapular)
Humerus supination muscle metabolic energy (Met_supinator)
Left-hand triceps metabolic energy (Met_tricep_LH)

3.2 Parametric Design Results

According to the kinematics analysis and inverse dynamics analysis of AnyBody, the relationship between muscle metabolism and position such as Height, posX, posZ can be obtained.

The parameters of evaluation are so many, so the relationship between total muscle metabolic energy and position is taken as an example while others are similar with total muscle metabolic energy.

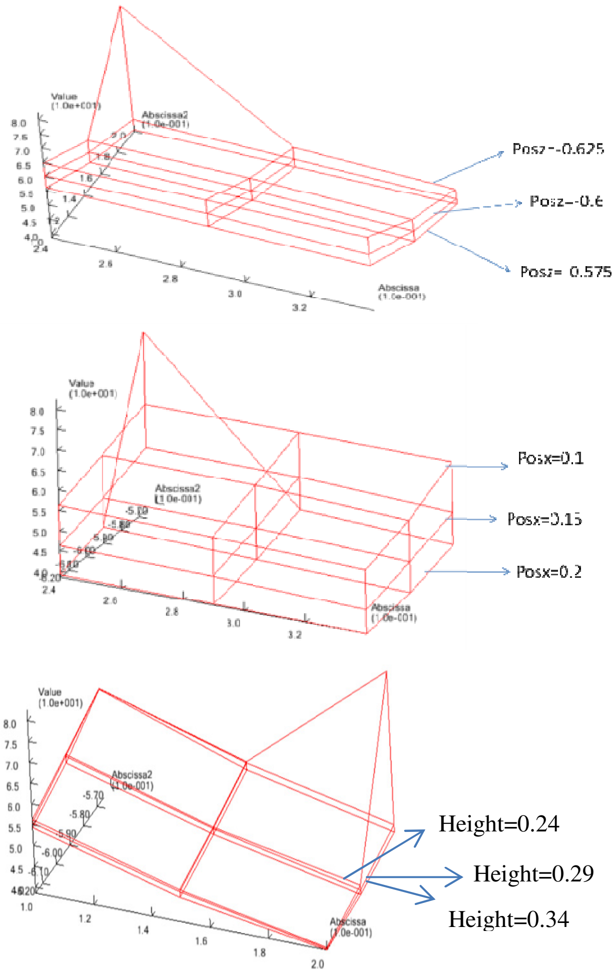

Fig. 5. The Relationship between total muscle metabolism and Height, posX, posZ

Based on the data of Fig.5, we can get:

1. Considering the three design variables, the change of posX plays the most important role in muscle metabolism.
2. In the cuboid consisted of three design variables, total muscle metabolism will suddenly change a lot in the lower right of the design space limit point (height = 0.24, posX = 0.2, posZ = -0.575).
3. As posZ changes from -0.625 to -0.575, the rod comes away from the pilot, total muscle metabolism will gradually decrease;
4. As posX changes from 0.1 to 0.2, the rod in the vertical direction moves away from the pilot, the total muscle metabolism will gradually decrease;
5. As Height changes from 0.24 to 0.34, the height of rod layout gradually increases, the total muscle metabolism will gradually decrease.

3.3 Optimal Design

Based on the six muscles selected already, the total of six muscles metabolism will be approximate as the total of all the muscles. [11] So the location of push-pull rod where pilot feel the least tired will be the least of total muscle metabolism. As posZ changes from -0.625 to -0.575, posX changes from 0.1 to 0.2, Height changes from 0.24 to 0.34, the location of min (metablism_all) can be searched out.

With two directions of the rod fixed, the other changes, minimum fixed can be obtained after changing the variable of direction. So on, the results are as follows:

The minimum of total muscle metabolism is 38.6N.m. The number of total iteration step is 19.

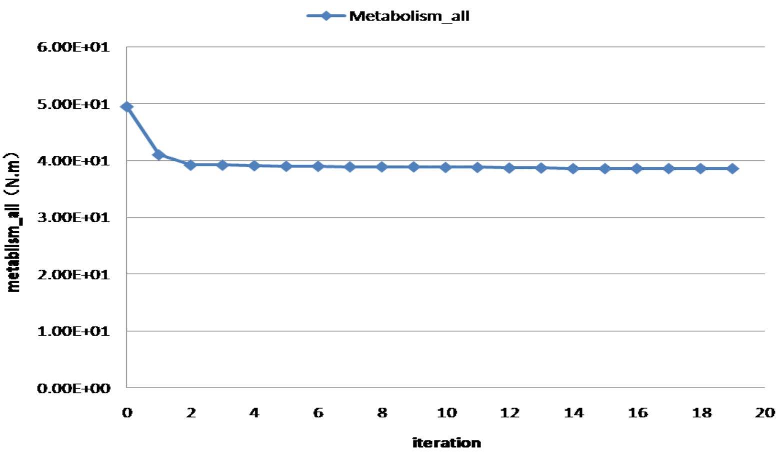

Fig. 6. Total muscle metabolism iteration diagram

According to the iteration between total muscle metabolism and Height, posX, posZ, optimal location of push-pull rod where the total muscle metabolism is least is Height = 0.319 posX = 0.2, posZ = -0.625.

4 Conclusion

This paper is based on the AnyBody modeling method of human motion of pushing and pulling push-pull rod. Faced with more than 190 muscles of right arm, six muscles are selected according to the size and the change as the location of rod changes. At the same time, as the location changes in a small room, we can get the optimal location of push-pull rod where the total muscle metabolism is least. As the result shows metabolism can provide an experimental basis for the design layout of the cockpit instruments, operating device. Furthermore, studies could continue on muscle activities, muscle forces and so on. More evaluation should be added for computing certain muscle forces. And other optimization algorithms should be used to compute muscle forces in more complicated situations.

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