Engineering Assessment in Biomechanics and Ergonomic Adoptable for Designer at Early Product Design Phase

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ABSTRACT

Occupational health get more concern in recent years, turning the ergonomic and human factor issues an essential consideration in product design process. In a survey presented in [4], over 90% of designers and engineers recognized that they needed to consider ergonomics earlier in the development processes. However, most of the assessment is done by engineers since designers always encountered technical difficulties to run such assessment. In this paper, we present a method for designers to adopt the engineering assessment for biomechanics and ergonomics on human posture at early product design phase. The aim is to allow designers to easily perform the design evaluation with minimal intensive technical training. The proposed method is implemented in the experiments to evaluate a sample workplace design for desktop work. Human motion data is captured and then applied to a digital human model and passed to assessment software to realize the human posture and evaluated based on existing ergonomic assessment scheme Rapid Upper Limb Assessment (RULA)[24].

Keywords: design process, ergonomic assessment, motion capture, upper limb disorder, occupational health

1. INTRODUCTION

The importance of applying ergonomics into design process could be illustrated by [34]. According to the report, there were 4.2 million occupational injuries and illnesses among U.S. workers, and at a rate of 4.6 cases per 100 full-time workers experiencing workplace injuries and illnesses. Musculoskeletal disorders, for example, shoulder pain, neck disorders and low back disorders occur if the posture of end user is not taken into consideration in product development. In the past, most of the posture and other ergonomic evaluation is not included in the design process, but carried out reactively, after injuries or problems occur. Moreover, the traditional method is always done manually by ergonomic experts themselves or by observing the users' behavior and the result could be sometimes subjective and incomplete. [13] presented the idea that the relative cost of correcting design errors will be increased if errors are found in latter stage in design process. Therefore the design evaluation on ergonomic issues should be carried out proactively in a quantitative way as early as possible in design process.

Recent years, the virtual environment and digital human models (DHMs) and other virtual reality technologies are involved into ergonomic assessment so the problem could be analyzed proactively in design process with producing more objective and all-rounded solution ([13], [20], [21]). The human motion could be simulated based on some inverse kinematics (IK) algorithms or predicted by human motion modeling methods such as adaptive feed forward models, control models, etc. ([1], [14], [19], [26], [36]). Several commercial systems developed from these technologies are available for ergonomic evaluation in posture, such as JACK [33] and AnyBody [3]. However, the software requires in-depth training on the modeling technique and task specification with biomechanical and human motion knowledge, which restricted the user to engineering or well-trained technician. The evaluation process may be too complicated and ineffective for designer if only several simple analyses and user-test are to be performed. By case studies, it is also found that the existing human motion simulation is not well modeled and could not predict realistic and valid population postures and motions ([8], [10]). So there are many studies try to gather the human motion data directly from subjects using optical or electromagnetic tracking devices. In such way, the complicated configuration and task specification of the evaluation software could be passed.

The purpose of this study is to propose a method that could be easily adopted by designer in the early design process to assess the posture risk by using the motion capture technologies.

2. EXPERIMENT SETUP

Experiments are performed to show how to run the complicated engineering assessment of posture analysis into a simplified one for designer to evaluate their own design. There are more and more ergonomic problems happen in modern office, thus a design of an office workplace for desktop work is chosen. In this paper, only the upper limb posture will be taken into account since it consists most of the risk factors in office work.

2.1. Workplace Design

A sample office workplace design is considered where the environment is laid out with a chair and a table in front. A keyboard, a mouse and a LCD monitor are placed on the table where subject could freely adjust their positions. At early design phase, what is needed for the posture analysis is the dimension of the design which provides enough information to guide the user posture. In such, there are a number of physical variables that we can investigate for assessment [18]. The outlook of the design is shown in figure 1. The magnitudes of all the parameters are given in table 1.

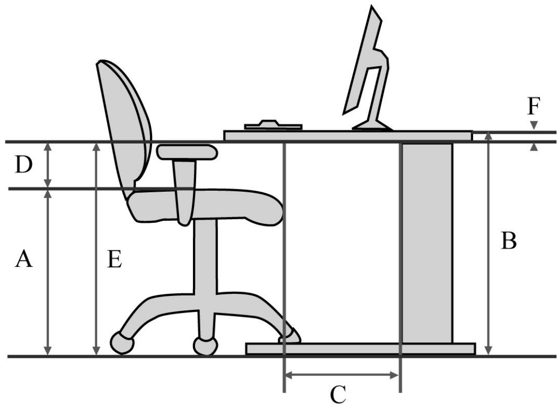

Figure 1. Workplace set-up

Table 1: Magnitude of workplace

Data Type	Magnitude (cm)
A (Seat Height)	42
B (Surface Height)	74
C (Leg Clearance)	60
D (Thigh Clearance)	30
E (Knee Clearance)	72
F (Surface Thickness)	2

2.2. Description of Subjects

7 subjects are invited to perform the experiments. Their anthropometrical data of subjects are listed in Table 2, with the data type referenced from [23]. Experiments are performed by each subject under the same workplace. Their motion data are applied to a digital human model for posture analysis.

Table 2: Anthropometrics data of the subjects

Data Type	Quantity (cm)	Standard Deviation (cm)
Body height	173.8	5.3
Hip width	36.3	2.0
Chest depth	23.3	1.9
Head height	24.3	1.7
Head width	18.8	0.8
Waist circumstance	88.2	6.2
Foot length	29.8	0.9
Sitting height	87.2	2.4
Buttock-knee length	46.9	4.7
Knee height sitting	55.7	2.4
Upper arm length	31.3	2.9
Forearm length	26.7	1.3
Forearm length with hand	45.7	2.7
Shoulder width deltoid	44.5	1.4

2.3. Task

During the experiment, each subject is asked to perform a 5 minutes desktop work in the workplace while typing is the main task but using mouse is also allowed. Posture assessment is then applied to evaluate subjects' upper limb posture to determine if any potential risk exists.

2.4. Digital Human Model

34 markers are attached on to the subjects' bodies, covering the trunk, neck, head and upper limbs. The configuration of markers is shown at figure 2. The marker positions are referenced from different anatomic landmarks ([2], [6]), and additional markers are added to gather more information in particular joint. An optical motion capture is used to capture the trajectories of the markers.

The hierarchy of the model is similar to Biovision BVH [32] file format but only including upper limbs (figure 3). The model is created by capturing an initial pose called T-stand. Joints (a connection between two bone segments) were defined and by closely approximate the markers on the equivalent joints. For example, the mid-point of two markers on wrists will form the joint centre of wrist. The formation of skeletal system is important to approximate the joint and to estimate the joint angle for posture analysis.

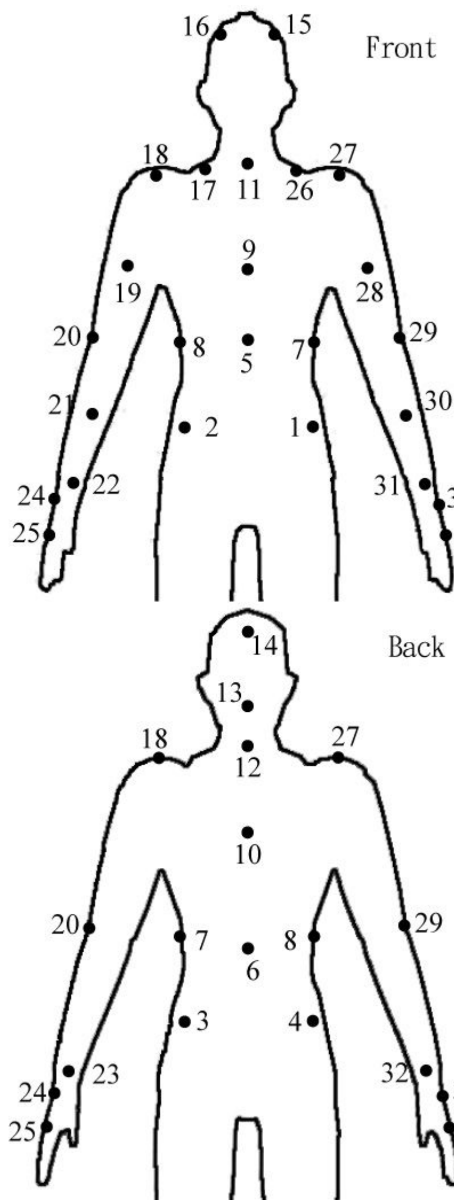

Figure 2. Marker Positions and Indexes

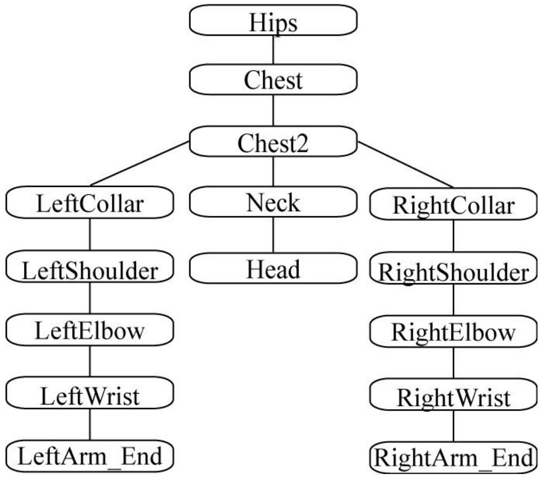

Figure 3. Parent-child hierarchy of upper human skeletal system

3. DATA ANALYSIS

3.1. Methodology

Once the motion data is captured, several methods could be adopted for postures assessment. Common methods include OWAS [12], Rapid Upper Limb Assessment [24] and Rapid Entire Body Assessment [17]. In this paper, the Rapid Upper Limb Assessment (RULA) is chosen.

RULA algorithm is used commonly to observe the risk of upper limb disorder contributed by postures, forces and muscle activities, the score sheet is shown in figure 6 [11]. This method is originally a survey-based observation tool. However, a quantitative assessment could be done by introducing the motion capture for motion data gathering. RULA uses a scoring system to indicate the comfort of posture, score one being the most comfortable/ideal posture.

Joint angles, twisting and bending of the arms, wrist, neck, trunk and legs are necessary for computation of RULA score. Other factors like weight of the load and muscle use are also counted in the scoring. The result score, called grand score, could be used to analyse a task for risk factor of postural fatigue, discomfort, or upper limb injuries.

There are 4 levels of grand score in RULA:
Level 1: Score 1 or 2 – acceptable posture if not maintained or repeated for long periods
Level 2: Score 3 or 4 – further investigation needed, may require changes
Level 3: Score 5 or 6 – investigation, changes required soon
Level 4: Score of 7 – investigation, changes required immediately.

RULA is chosen as it could convert the complicated posture information into different categories and provide warning for possible risk. The result score is easy to understand and the risk limb could be easily localized.

3.2. Joint Angles Estimation

By using the skeletal human model mentioned before, the joint angle is estimated by comparing the change of the angle between the limb segments referenced to the natural posture on a plane-of-view, while the information of natural posture could be referenced to the initial T-stand. There are mainly three plane-of-view used in the angle estimation, side-view, front-view and top-view. For instance, the lower arm angle could be found as in figure 4 using the side-view. And the neck twisting could be found as in figure 5 using the top-view.

One case in the calculation need to be aware is the wrist twist estimation, in which the plane for twisting varies with hand motion. The wrist twisting could be found by dividing the forearm motion to rotation followed by twisting [35]. That means the forearm motion should be localized from the elbow and shoulder movement, the residue will become the wrist twisting, as shown in equation (1).

$$v'^{t}_{wrist} = R^{Elbow}_{Wrist}(t) \times R^{Shoulder}_{Elbow}(t) \times v^{t}_{wrist} \quad (1)$$

$R^{x}_{y}(t)$: Local Rotation matrix from x to y at time t

v^{t}_{wrist} : Global vector of wrist formed by vector of marker 31 to 32 at time t

v'^{t}_{wrist} : Local vector of wrist at time t

The rotation axis for wrist twisting is near to the forearm. And the wrist twist angle could be found by referencing to the natural orientation of the wrist.

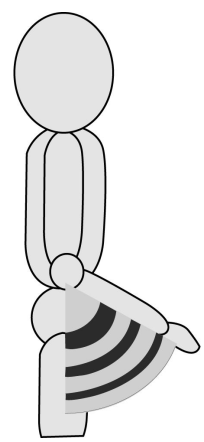

Figure 4. Estimation of lower arm joint angle. The angle is computed by the angle between current lower arm and the vertical line.

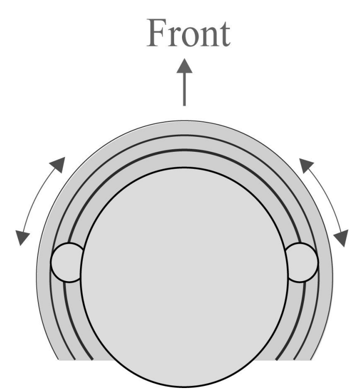

Figure 5. Neck twist computation. The angle is calculation by the angle between the current direction and the front direction of body

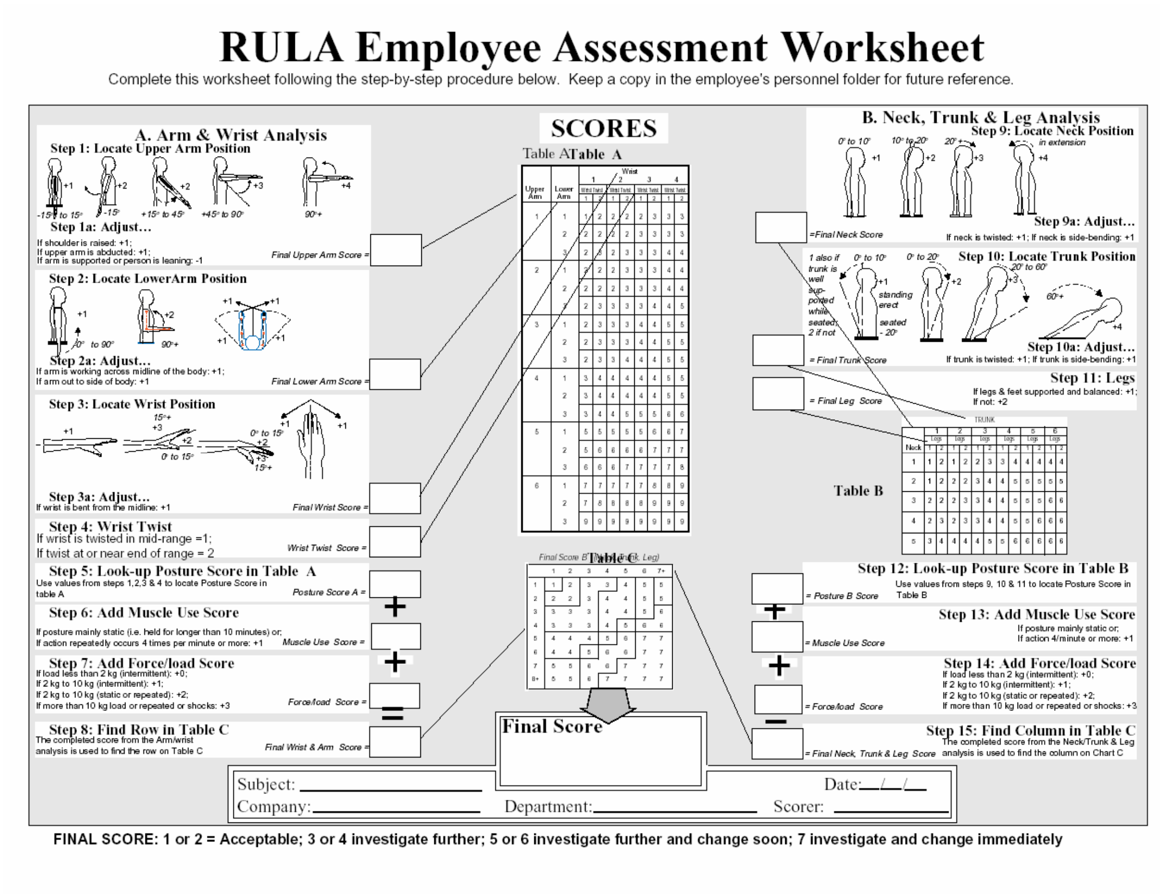

Figure 6. RULA score sheet

4. RESULT AND DISCUSSION

The subjects are invited to perform the task in the same environment. Software is written to automatically convert the raw marker trajectories to the digital human model, estimate the joint angle and calculate the grand score of RULA. Table 3 and table 4 show the detail joint angle and the average score of their posture in the whole period respectively. The result is used as a guidance to improve the design.

It is noted that the wrist-twisting angle is relatively large in the experiment period, in which typing and mouse-use are the most frequent motions. The calculation assumed that the reference wrist vector is placed vertically while the wrist orientation in typing and mouse-use are relatively horizontal. If subject tries to turn the wrist in an anticlockwise direction, it is found that the range of further twisting is small. Thus it is correct that the normal typing task has a large angle of wrist twisting.

The supported forearm may reduce the tension on the muscle provided by twisting so the effect of twisting to the overall posture, especially in typing task, is relatively insignificant even the magnitude of angle is large. RULA just specifies that an additional score should be given if wrist is twisted nearly to the limit, but not specified what is "near". Further studies may be required on how the wrist-twisting angle may relate to the upper limb disorder.

Table 3: Details of Joint Angle and Joint Motion in the experiments. "Occurrence" means how often that type of motion occurs in the experiments

Type		Average Angle	Standard Deviation	Occurrence (%)
Group A	UpperArm	34.5	7.3	-
	UpperArm Raise	-	-	59.0
	UpperArm Abduct	-	-	100.0
	Lower Arm	96.3	3.5	-
	Lower Arm From Midline	-	-	0.0
	Lower Arm Bent to Outside	-	-	69.9
	Wrist	10.9	5.6	-
	Wrist From Midline	9.7	4.1	0.0
	Wrist Twist	95.8	19.8	58.3
Group B	Neck	-6.1	3.8	-
	Neck Twist	1.3	9.6	1.6
	Neck Bend	2.4	2.6	0.3
	Trunk	11.3	1.3	-
	Trunk Twist	1.1	0.6	0.0
	Trunk Bend	0.6	0.4	0.0

Table 4: Score of RULA of the experiments with initial setting

Score Type	Average Score	Standard Deviation
Upper Arm	2.6	0.5
Lower Arm	1.8	0.6
Wrist	2.2	0.5
Wrist Twist	1.6	0.5
Neck	1.2	0.4
Trunk	2.0	0.0
Score C	4.7	0.5
Score D	3.0	0.2
Grand Score	3.7	0.5

From the result, the mean score of all subjects, falling into Level 2 in the RULA score, shows that the posture is not comfortable and may require changes. The environment may induce risk for upper limb disorders for prolonged work. When the individual score is being reviewed, the upper arm score and the wrist score are relatively high and are contributed to the high grand score. By taking a detail analysis of the joint angles, it is found that the shoulder is often elevated and the arm is always abducted, it shows that the table height maybe relatively high when compared with the sitting height to most of the subjects. Relatively large upper arm abduction will be formed, which raise the shoulder. This could lead to shoulder pain [16] and inflammations of tendons or tendon sheaths in the forearms for prolonged work [15].

A remedy is made to increase the seat height, or lower the table, according to the design requirement for target user, so that the joint angles could be falling into a comfortable range. Posture in the modified workplace is captured and the score is reduced, as shown in table 5.

The score is still fall into Level 2 in RULA due to the relatively high wrist score. However, if wrist is supported, the risk of upper limb disorder could be greatly reduced [15], while RULA scoring doesn't have a function to indicate the work of wrist support. Thus the modified design should be able to produce a more comfortable workplace.

Table 5: Score of RULA of the modified design

Score Type	Average Score	Standard Deviation
Upper Arm	1.1	0.3
Lower Arm	1.7	0.5
Wrist	3.0	0.2
Wrist Twist	1.7	0.5
Neck	1.0	0.4
Trunk	2.0	0.1
Score C	3.8	0.6
Score D	3.1	0.4
Grand Score	3.2	0.5

All in all, the engineering assessment on posture is successfully applied to design evaluation to remove basic risk factors from the design, which would lead to upper limb injuries.

5. CONCLUSION

Upper limb injuries and other occupational health problem are found more often in modern world together with the increased static and repetitive work in office. Increasing health concern of people is leading to higher rate of compensation for occupational disease [5]. Therefore more companies are concern on occupational safe.

Small/medium design enterprises may not have the resource to assess their product for ergonomic and occupational health issues, while big companies are mainly perform such evaluation until the design is passed to engineer in late design phase. Iterative process is costly and ineffective if ergonomic problem is found in the design and need to be returned to the designer. Small/medium design enterprises could increase their competitiveness and product quality if simple design evaluation on ergonomic issue could be performed. Even large companies could be benefit if they could assess their design earlier in the design process.

The engineering assessment method proposed in this paper provides a simple, automatic and continuous posture risk assessment cooperated with motion capture technology that is easy to be adopted by designer. The computation of data is fully automatic. With basic knowledge on motion capture and experience in building simple geometric models, the evaluation method could be applied for designer to run simple user-test in early design phase. Iterative design and communication procedure between designer and engineer could be reduced. The proposed method also gives flexibility and extensity to implement other risk assessments and perform more precise posture analysis and research if needed.

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