CIRP Annals - Manufacturing Technology 62 (2013) 13–16

Contents lists available at SciVerse ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

# Automatic estimation of the ergonomics parameters of assembly operations

Atsuko Enomoto (3)[a,*], Noriaki Yamamoto (3)[a], Tatsuya Suzuki (3)[b]

[a] *Hitachi, Ltd., Yokohama Research Laboratory, Yokohama, Japan*
[b] *Hitachi, Ltd., Infrastructure Systems Company, Hitachi, Japan*

Submitted by Tamio Arai (1), Tokyo, Japan

ARTICLE INFO

*Keywords:*
Assembly
Virtual reality
Ergonomics

ABSTRACT

The ergonomics of assembly operations affects standard operation times and assembly reliability. It is a complicated time-consuming task to estimate the ergonomics parameters of operations in assembly cells. Assembly operations are simulated in a virtual environment, and ergonomic parameters including the visibility of an assembling part, posture and reachability of an operator are quantified automatically by using images of the assembling part which are automatically generated. The highest score among the image is selected as the ergonomics score of the assembly operation. The proposed method is tested by applying it to the assembly operations of a PC. Results demonstrated the feasibility of the proposed method.



## 1. Introduction

The assembly processes of production have become more globalized, and product models have been diversified recently. In this business environment, a pre-consideration of the ergonomics of assembly operations becomes increasingly important to ensure assembly reliability and to reduce standard operation time. Simulation with a human model in a digital mock-up (DMU) is an effective approach to evaluate the ergonomics parameters [1–4]. Because this task is complicated and time consuming, several solutions were proposed to overcome that. An agent system, cooperating with a human operator to aid the complex operations was proposed [5]. Currently, not only the physical stress but also mental stress assessment of an operator have been proposed [6]. One of the difficulties of ergonomics simulation is to set the posture of a human model. A solution to this difficulty, posture prediction of a human model with a neural network based approach has been proposed [7]. However, this method required several sample postures in each operation for training of the neural network. Therefore, the difficulty of the posture setting was remained. Overall, ergonomics can be simulated recently much more precisely and accurately.

However, the use of the ergonomics simulation with a human model needs still high cost investment. Therefore, mainly applied areas are limited to mass production lines like automotives [3] or assembly lines of expensive products like aircrafts [4].

On the other hand, in assembly cells like inexpensive or custom made products, it is too expensive to use the ergonomics simulation with a human model. In these areas, design for manufacturability (DFM) has been used upon for decades as a inexpensive and effective assessment method that includes the ergonomics issues of an operator. In DFM assessment, the posture of an operator and the visibility of an operation are the key parameters that affect defective rates of operation [8–12].

Currently, most input data of DFM assessment are possible to obtain from features of CAD models. However, the posture of an operator and the visibility of an operation are still input manually. Therefore, utilization of DFM is difficult for products which have large number of parts or which product life cycles are short. One of goals of our study is to overcome such difficulties of use of DFM. The development of a methodology of scoring and ranking a number of important parameters concerning the ergonomic feasibility of assembly operations are developed. We propose an automatic estimation method of four ergonomics parameters; visibility of the assembly operation, eye sight direction against an assembly motion, reachability of the operation and glance load to the operator's neck. In our method, we estimate these ergonomics parameters based on captured images of the assembling operation by multi directed virtual cameras to a part in 3D graphics. In DFM assessment, it is not necessary to simulate the posture of the operator precisely. Those ergonomics parameters are selected from several levels.

This paper consists on the following sections. In Section 2, the concept of the proposed method is discussed. Section 3 describes automatic estimation of the visibility based on captured images. In Section 4, the scoring of ergonomics parameters is discussed. In Section 5, we present the ergonomics scores of a PC assembly sequence to verify the feasibility of the proposed method.

## 2. Concept of automatic estimation method

We assume that an operator always tries to take a position and posture (pose) in which the part requiring assembly is clearly visible. We define this pose taken by the operator as the optimum pose. In automatic estimation of the ergonomics parameters, we introduce a virtual camera which represents eyes of an operator and the captured images are assumed as equal to the field of views of the operator. Plural cameras are pointed from multi-directions to the assembling part and each camera respectively captures images of the part. The subject is how to select the camera which is the closest

* Corresponding author.

0007-8506/$ – see front matter © 2013 CIRP.
http://dx.doi.org/10.1016/j.cirp.2013.03.038

to the optimum pose supposed to be taken by the operator. For this subject, the captured images and camera poses are obtained to estimate four ergonomics parameters as previously mentioned in Section 1.

First, captured images are explained. Fig. 1 shows an example of an assembling operation of sub-assembly of a PCB unit. The sub-assembly is placed on a work table and multi-directed cameras are surrounding the work table. In the image (b) in Fig. 1, an assembled part coloured red is clearly visible. However, in the image (a) in Fig. 1, the assembled part is partially hidden by previously assembled PCB-chassis. If the assembled part is hidden by previously assembled PCB-chassis, its visible area on the assembled part is decreased. Therefore, the visible area of the part is estimated according to the image visibility of the a camera, whose axis represents the eye sight direction of the operator to the assembling part. It is preferable that the direction of assembly motion matches that of the eye sight.

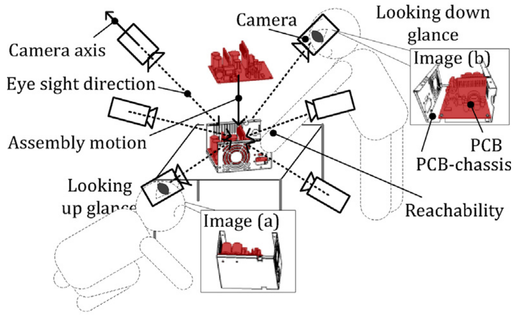


**Fig. 1.** Multi-directional camera poses to search for operator's optimum position and posture.

Next, we discuss about utilisation of camera poses. A camera represents the eyes of the operator as described above. The direction of motion matches that of the eye sight direction. The glance depends on the eye sight direction. If the glance is looking up, it loads to the neck of the operator which should be avoidable. We assume the distance between the operator's eyes and the assembled part represents the operator's reachability to the assembled position of the part.

Each camera pose is scored by above 4 ergonomics parameters, then a camera pose with the highest score is selected as the optimum pose which is supposed to be taken by an operator. Also, the highest score is taken as the estimated ergonomics score. This is the basic concept of the automatic estimation method.

## 3. Automatic capturing of image of assembly operation

In this section, we describe how the camera poses are calculated. Let a camera located on a sphere surrounding the work table at equal intervals on a latitude line and at three points on a longitude, as shown in Fig. 2. Three different heights represent the operator's postures; standing, half-sitting, and squatting.

Let a camera be located on a sphere at the latitude $j$ ($j = 1,2,3$) and the longitude $i$ ($i = 1,\ldots,n$), then it has a pose of camera ($i,j$) $R_c(i,\ j) = [x_c(i,\ j)\, y_c(i,\ j)\, z_c(i,\ j)]$. $\mathbf{O}_c(i,j)$ is the position vector of the origin of camera($i,j$). The **x** axis of camera($i,j$) is called $\mathbf{x}_c(i,j)$. Let $\mathbf{x}_c(i,j)$ be always parallel to horizontal plane **xy** and tangent direction of the circle surrounding the work table. The **z** axis of the camera($i,j$), i.e., $\mathbf{z}_c(i,j)$, is directed toward **r** which is the centre point of the bounding box of the assembled part in the 3D model. Resultantly the posture of camera($i,j$) is defined as follows:

$$\boldsymbol{z}_c(i,\ j) = \frac{\boldsymbol{O}_c(i,\ j) - \boldsymbol{r}}{|\boldsymbol{O}_c(i,\ j) - \boldsymbol{r}|} \qquad (1)$$
$$\boldsymbol{y}_c(i,\ j) = \boldsymbol{z}_c(i,\ j) \times \boldsymbol{x}_c(i,\ j)$$

Next, we evaluate the visibility of the part to be assembled on these 3 by $n$ poses.

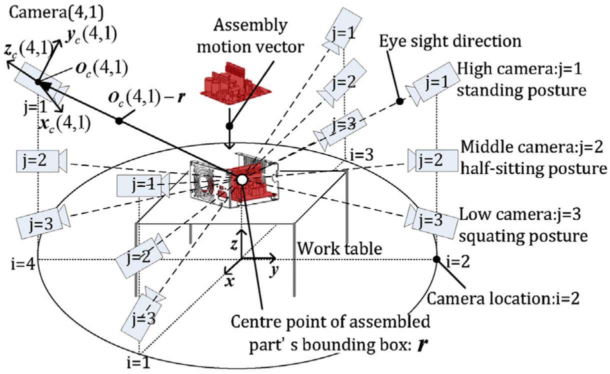


**Fig. 2.** Camera poses: 4 locations by 3 postures.

In Fig. 3 (1), three poses for each camera location are calculated, and in each pose, the camera captures the image of the part to be assembled. From each image and camera pose. In (2), 4 ergonomics parameters make up the ergonomics score in each assembly operation. The details will be discussed in Section 4. In (3), the highest ergonomics score is selected and we take this score as the estimation result of the ergonomics score of the assembly operation. In (4), the total scores of the assembly sequence is made up.

## 4. Scoring method of the ergonomics parameters

In this section, we discuss our scoring method of the ergonomics parameters of an assembly operation, including visibility, reachability, eye sight direction and glance, and how to make up the total ergonomics score of the assembly sequence from four scores of ergonomics parameters of each assembly operation.

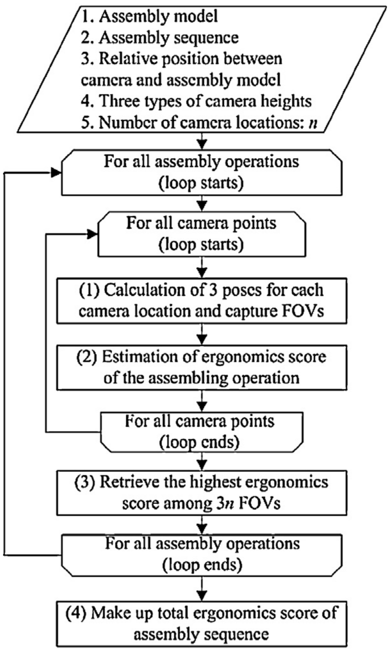


**Fig. 3.** Automatic estimation of ergonomics score of assembly sequence.

### 4.1. Visibility of assembly operation

To estimate the visibility of an assembly operation, two images captured by each camera described in Section 3 are compared. In one image, all previously assembled parts and the assembling part are displayed in the assembly model ((a) in Fig. 4). In the other image, only the assembling part is displayed and other parts are hidden ((b) in Fig. 4). In both images, surfaces of the assembling part are highlighted in red (Fig. 4).

Then, the number of pixels of red coloured in two images are counted automatically. $V_a(i,j)$ is the number of red colour pixels in