Journal of Manufacturing Systems 33 (2014) 699–710

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

Technical Paper

Ergonomic job rotation strategy based on an automated RGB-D anthropometric measuring system

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ARTICLE INFO

Article history:
Received 15 August 2013
Received in revised form 20 February 2014
Accepted 22 February 2014
Available online 22 March 2014

Keywords:
Job rotation
RGB-D camera
Anthropometric measurements
Particle swarm optimization

ABSTRACT

Ergonomic job rotation is a novel strategy to increase work efficiency and decrease work fatigue of the operators in manufacturing lines. In this paper, we proposed an automated anthropometric measuring system based on RGB-D camera and a job rotation strategy based on particle swarm optimization (PSO). The first training stage involved a series of 3D data-processing techniques to generate parametric models from scanning human database. The second stage can estimate the anthropometric measurements from the depth maps captured by RGB-D camera system. Finally, a novel job rotation strategy is proposed with PSO based on three target functions, which are designed to measure the work discomfort levels and risks. The experimental data is a real case which includes the operators of a quartz blanks manufacturing line. The experimental results show that our proposed system can effectively and dramatically reduce the average risk and decrease the number of operators who experienced either a high risk or a medium risk levels.

1. Introduction

Job rotation has received a considerable amount of attention because it is an effective method for increasing work efficiency and decreasing work fatigue and its associated risks. When applying this management technique in manufacturing, operators are alternated among two or three jobs to reduce the incidence of work-related musculoskeletal disorders (WMSDs). Even though the working environment is not physically improved, our proposed ergonomic job rotation strategy effectively increases the concentration and job satisfaction of operators. It also increases the work motivation and improves the professional skills, which is highly relevant to the loyalty of employees.

Job assignment is a fundamental research topic regarding job rotation. Various methods have been proposed to appropriately assign a fixed number of tasks to each operator. Ergonomic job rotation strategies are designed to reduce the average risk of acute or cumulative WMSDs that operators in a production line may experience. The focus of previous research has been on job content or the physical facilities at work. Few studies have addressed the influence of the characteristics of an operator, such as height, arm length, and gender, as well as the fitness requirements of various workstations. The ergonomic design of a single workstation and the overall layout of manufacturing systems [1] have been widely discussed in research of facility planning [36]. Because of the high expenditure and long overhaul time, dynamically redesigning and changing the physical layout of production lines is impractical. Implementing job rotation and the operator assignment strategy can economically and efficiently reduce WMSDs because operators are assigned to workstations that are suited to their individual characteristics.

This paper presents an ergonomic job rotation strategy based on individual anthropometric measurements, which are estimated automatically by using an RGB-D camera system. Job assignment decisions are determined based on the detailed attributes of each job, the environmental constraints of each workstation, and the predicted human dimensions of each operator. The results of experiments show that the proposed system can improve industrial safety and health by substantially reducing the average ergonomic risks and the number of operators who are exposed to high-risk working conditions.

Anthropometry, referring to measurements of the human body, plays an important role in job design, manufacturing system [1], and human-centered design [37,38]. Most countries have defined the suggested anthropometry standards for different workstation, and related international standards have been published as well, such as ISO 11226:2000, ISO 11228-1:2003, and ISO 14738:2002. In traditional, anthropometric dimensions are acquiring by using simple instruments such as calipers and compasses. However, the time

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http://dx.doi.org/10.1016/j.jmsy.2014.02.005
0278-6125/

consumption is relatively high, and the measurement precision cannot be guaranteed. With the rapid development of 3D scanning technology, researchers can collect large amounts of body-scan data efficiently and economically. Lu and Wang [2] developed an automated anthropometric data collection system from a 3D body scanner. Twelve landmarks and three characteristic lines were extracted, and 104 anthropometric data can be calculated.

However, the use of expensive 3D body scanners increases the costs of customized products and restricts applications. Various automatic human dimension extraction algorithms have been developed without using a 3D scanner. Lin and Wang [3] presented an automated approach to detect human body feature points from 2D images, and 60 feature points can be extracted automatically by using this method. Hung et al. [4] proposed a method to obtain anthropometric measurements from photographic images; six linear and four circumferential measurements were obtained using the proposed method. In addition to image-processing or 3D modeling techniques, commercial RGB-D cameras, such as the Microsoft Kinect and ASUS Xtion, provide another possibility to solve the problem with pairs of color images and depth images in real time. Velardo and Dugelay [5] applied pattern recognition techniques in in-depth images, and proposed a height, weight, and gender prediction system. With similar techniques, Loconsole et al. [6] proposed a marker-less tracking algorithm to estimate facial anthropometric measurements. However, the robustness and precision of the measurements still limit the applications.

Repetitive and regular motion can cause WMSDs, which are a common occupational disease in manufacturing. Job rotation is a method that can reduce the incidence of WMSDs and boredom. The relationship between job rotation and WMSDs has been discussed in previous studies [7–10]. The work presented by Frazer et al. [7] addressed the relationship between the job rotation effect and low back pain based on the Time Weighted Average approach. They measure the peak L4/L5 shear force and the cumulative moment to evaluate the probability of reporting low back pain. Otto and Scholl [8] examined various methods for designing effective job-rotation schedules to reduce ergonomic risks. Xu et al. [9] focused on hazard exposure in the extremities of the upper body by presenting an ergonomic-center method for task assignment in assembly-line design. Linear models were developed to establish relationships between task assignment and ergonomic measures of the upper extremities. Asensio-Cuesta et al. [10] presented a multi-criteria genetic algorithm for generating job rotation schedules and classified ergonomic criteria into three categories, namely, ergonomic, physical skill, and competence, to reduce the incidence of WMSDs caused by the accumulative effects of fatigue. Subsequently, each job in the rotation was rated according to weights assigned to each criterion. Jorgensen et al. [31] adopted a questionnaire to survey the practices of job rotation strategies in Midwest US manufacturing companies. The questionnaire contained five categories which could thoroughly survey the reasons of implementing job rotation, the factors influencing job rotation schemes, the adopted methods to define the schemes, and the limitations and benefits of implementation of job rotation. Their results show that only 42.7% companies implement job rotations as the suggestions of NIOSH and OSHA.

In addition to ergonomic concerns, environmental and physical considerations are applied to job rotation problems. Carnahan et al. [11] developed methods of incorporating safety criteria into scheduling algorithms to produce job rotation schedules. Two different methods were implemented in designing job-rotation schedules: integer programming and a genetic algorithm (GA). The difference between lifting capacity and gender was considered in the study. Diego-Mas et al. [12] developed a GA-based method, in which multiple factors, namely, movement, general capacity, mental capacity, and communication capacity, were considered. The scoring system is used to assign each factor a weight according to the frequency of movement and the capacity to perform the movement. Asensio-Cuesta et al. [13] applied the Occupational Repetitive Actions (OCRA) ergonomic assessment method to the GA-based method. The OCRA method was used in considering collective ergonomic risk factors, such as frequency and postures, as well as mechanical, environmental, and organizational factors. Several literatures addressed studies about job rotation from different viewpoints, such as economic and intangible factors. The cost and benefits of job rotation strategies is discussed in the work of Metin and Miceli [32] from the perspective of enterprises. Two factors are defined to be the key factors that affect the job rotations strategies. The first one is a combination of various attributes including lifetime tenure, profit sharing, and job participation. The other one is the innovativeness. However, these factors still have different influences in varying industries and companies. Azizi et al. [33] presented a work which focuses on how to ease boredom and exploit the rotation effect. The boredom and rotation effect, such as forgetting skills and learning in short period of time, are two key variations in job rotation strategy. They established a generic model which contains these factors in rotation strategy.

Most current methods apply a global optimization method to balance the work load and prevent bad working postures. The goal of these systems is to decrease the risk of WMSDs and minimize the cumulative ergonomic hazards. However, the characteristics of the individual operator are often not considered. As an ergonomic research, the operator assignment task in this paper might be restricted by the layout of a workstation or the characteristics of a job. To model the congenital variations of operators into job rotation strategy can decrease WMSDs dramatically. Also, new operators can be matched to appropriate jobs based on their estimated physical characteristics.

In this study, a human dimensions estimation sub-system, which combines the advantages of a real-time low-cost RGB-D camera system and a three-dimensional (3D) scanning body database, was used to rapidly predict anthropometric measurements of each operator in manufacturing lines. The RGB-D camera was used to capture the surface geometry information of each individual, which enabled rapid estimation of the human dimensions. The proposed system consisted of three major stages. The first stage was the training stage, which involved a series of data-processing techniques, such as 3D model alignment, resampling, and principal component analysis (PCA), to generate statistical parametric models between the dense 3D point cloud data of the scanned human body and the corresponding anthropometric measurements. The second stage was the testing stage, in which the depth maps from the coordinates of the RGB-D camera were converted to the real 3D world. The real-time scanned data was then transformed to acquire the estimated anthropometric measurements through a series of computational processes, including iterative closest point algorithm, PCA, and pre-learned parametric models. In the third stage, the proposed job rotation system was based on the particle swarm optimization (PSO) algorithm. Various risk evaluation mechanisms were defined according to the ergonomic design principles of each workstation or job. The estimated measurements of each operator from the RGB-D camera were used to determine the fitness for each job. The target functions of optimal job assignments and rotations are also developed based on the global fitness measurements.

2. Proposed methods

A novel job rotation method is proposed based on ergonomic human dimensions of operators, which the automated RGB-D anthropometric measuring system estimates. The RGB-D camera and the 3D human model database can automatically obtain anthropometric measurements of the human body in real time,