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Multi Performance Research Methodology for Ergonomic Evaluation of Automated Guided Vehicle (AGV) Operators

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ABSTRACT
This work aimed at enriching a research theme, focused on exploiting the performance in a Human-Computer Integrated Manufacturing (HCIM) sys-tem using Automated Guided Vehicle (AGV) interface. A salient contribution of this research effort focused on adopting the concept of a load cell for the system of human-performance measurement. The developed novel sys-tem is capable of measuring cognitive and motor action responses simultaneously. The performance measurement system designed for this work may be replicated in other fields where systems are operated through control panels and where the responses of mentally retarded human beings (or the human beings with the symptoms of Alzheimer disease) are to be observed and evaluated. The research methodology designed in this work can be directly applied to the practical field to evaluate the performance of various human-panel operated system interface. The present work can be quite useful for the system designers of tomorrow.
Keywords-Applied force, Load cell, Multi-performance, Motor action time, Search time, Select time

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I. INTRODUCTION

Ergonomics in the workplace has to do largely with the safety of employees, both long and short term. Ergonomics can help reduce costs by improving safety. Ergonomists play an important role in evolving an optimal design of human-machine systems. Among the varieties of human-machine systems, Human-Computer Integrated Manufacturing (HCIM) system interface using Automated Guided Vehicle (AGV) represents one of the most widely used systems that challenges the ergonomists in designing and developing the model that might resolve many organismic and environmental problems linked with the usage of CIM sys-tem. Review of literature suggests that the original sources of postural stresses may be traced in terms of poor AGV workstation design. Inrecent years, the major emphasis is on preventing musculoskeletal injuries in the workplace. These injuries create a significant cost for the industry.

Relatively less amount of literature is available concerning Human-Computer Integrated Manufacturing (HCIM) system interface design. Hence, it is important to develop Ergonomic database that can quantify the effects of Automated Guided Vehicle (AGV) panel height, angle and operators working distance on human performance. The design of the workstation needs to take into account the adjustability of the working platform, clearances under work surface, AGV panel and display support devices. The effectiveness with which operators perform their tasks at consoles or instrument panels depends in part on how well the equipment is designed to minimize parallax in viewing displays, allow ready manipulation of controls and provide adequate space and support for the operator. In the past, studies were conducted to investigate physical impairments caused to the operators due to various factors related to the machining operation. Discomfort might be used as a measure for quantifying postural stresses [1].

([2], [3], [4], [5], [6] and [7]), researchers evaluated the effect of working postures on human performance in a computer numerically controlled (CNC) ma-chine environment. Assessments of the performance indicated a significant effect of levels of angle of abduction and viewing angle.

The focus of cognitive ergonomics is on the reciprocal influence between work and mind. Although cognitive ergonomics has much in common with cognitive psychology, the purpose is not to try to understand the nature of human cognition, but rather to describe how human cognition affects work and is affected by work [4]. The concerned areas of cognitive ergonomics include cooperative work, user interface design, modelling of users and systems, problem solving, learning and system design- especially the design of automation. Improving adaptability necessarily implies a focus on the human operator, the center of manufacturing processes. The adaptable production system has more explicit human cognitive requirements than manufacturing systems based on a mass production model and places more pronounced cognitive demands on individuals. Many researchers have addressed the problems associated with cognitive environments [8]. With the continued advancement of technology, operators are often responsible for performing several tasks simultaneously, which increases the relative load associated with task performance [8].

The literature review on the effects on human performance indicates the need of separate interface designs for various age group individuals. It is also ob-served from the literature that the cognitive and motor performances of peoples vary with the age.

II. INTERFACE DESIGN METHODOLOGY

As evident from the preceding discussion, the effects of anthropometric considerations like machine panel height, working distance, and panel angle on human performance, particularly in the context of human-CIM system interface using AGV are still not fully understood and thus, there exists a wide scope to investigate these effects. Accordingly, the HCIM system interface design using AGV methodology for the present work was formulated. There has been a rapid growth in the use of AGV. With the AGV applications getting more widespread at the global level, the musculoskeletal problems associated with these machines have also been generating more concern. The automated technologies get much more popular day by day. However, the pace of research in the field of HCIM system interface environment has been rather slow in comparison to the growth rate of AGV not only in developed nations but also in developing countries like India. Human problems associated with the HCIM system interface environment constitute one of the major research areas determining the extent and rate of success within the framework of effective and fruitful use of modern day automated technologies. There remains a dire need of catering to the demands of designers, manufacturers, purchasers and users regarding how automated machine systems could be made more useful, easier, faster, efficient and compatible for operation, from ergonomics point of view. The literature surveyed indicated that previous researchers by and large, have been mainly emphasizing the need to design and develop varieties of automated machine systems. In the recent era of highly competitive business environment, that is automated technology based, ergonomist cannot afford to remain ignorant of what is happening all around. The growth in the use of AGV has brought many subtle issues/problems pertaining to their effective utilization from human efficiency and comfort viewpoints. These problems get further aggravated when automated technology systems are used excessively in the kind of environments that are not conducive to their users. In this background, various studies could be designed to provide answers to some of the basic issues related to the use of CIM system.

In the designed studies, human performances can be measured in terms of search time, select time, motor action time and applied force. These performance measure features could be selected in the light of previous researches [9]. A pilot study could be conducted to determine the discrete levels of the HCIM system interface using AGV parameters that could help to operate an AGV, efficiently and comfortably. It is proposed to conduct the experiments based on *Taguchi's experimental design* for which an *appropriate orthogonal array (OA)* should be selected. As an illustration, for a study with three parameters and their corresponding three levels, an L_{27} orthogonal array with 27 rows (corresponding to the number of experiments) would be chosen for the investigations. The L_{27} (3^3) is an OA of 27 distinct rows and provide 26 degrees of freedom for studying different effects. This design matrix can be used to examine a maximum of 26/2 = 13 two-df effects. Thus, the L_{27} can be used to accommodate a full 3^3factorial design.

Search time, select time, motor action time and applied force generally acts as response variables to evaluate the AGV operator's performance. A full factorial design (based on L_{27} orthogonal array) of experiments consisting of 27 (3^3) experiments can be used to collect data for human performance. The collected data could be analyzed using grey relational analysis and analysis of variance (ANOVA). The concerned analysis steps are described below:

II.1. Grey Relational Analysis

The Grey relational grade is an index which represents multiple performance characteristics. It basically shows relations among the series of experimental results. The determination of grey relational grade requires preprocessing of the experimental data in order to transfer the original sequence to a comparable sequence. The procedures of signal-to-noise (S/N) ratio determination, data preprocessing and determination of grey relational coefficient and grey relational grade are described as follows:

II.1.1. Signal-to-Noise Ratio

Taguchi method is one of the simplest and effective approaches for parameter design and experimental planning. In this method the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (standard deviation [SD]) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the SD. There are three types of S/N ratios depending on the type of characteristics- the lower the better, the higher the better and the nominal the better.

The S/N ratios are expressed on a decibel scale. Regardless of category of the performance characteristics, a greater value corresponds to a better performance.

II.1.2. Data Pre-processing

In grey relational analysis, the function of factors is neglected in situations where the range of the sequence is large or the standard value is enormous. However, this analysis might produce incorrect results if the factors, goals and directions are different. Therefore, one has to pre-process the data which is related to a group of sequences, which is called "Grey relational generation" [10] and [11]. Data pre-processing is a method of transferring the original sequence to a comparable sequence. For this purpose, the experimental data is normalized in the range between *'zero'* and *'one'*.

II.1.3. Grey Relational Coefficient and Grey Relational Grade

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental data. The grey relational coefficient can be expressed as follows,equation (1)[12]:

$$\xi_i(k) = \frac{\Delta_{min} + \varsigma.\Delta_{max}}{\Delta_{0i\,(k)} + \varsigma.\Delta_{max}} \qquad (1)$$

Where $\Delta_{0i\,(k)}$ is the deviation sequence of the reference sequence $x_0^*(k)$ and the comparability sequence$x_i^*(k)$, namely:

$$\Delta_{0i\,(k)} = \|x_0^*(k) - x_i^*(k)\|,$$
$$\Delta_{max} = max_{\forall j \epsilon i}\, max_{\forall k}\left\|x_0^*(k) - x_j^*(k)\right\|,$$
$$\Delta_{min} = min_{\forall j \epsilon i}\, min_{\forall k}\left\|x_0^*(k) - x_j^*(k)\right\|$$

Where 'ς' is distinguishing or identification coefficient: $\varsigma \epsilon [0,1]$, ς = 0.5 is generally used.

After obtaining the grey relational coefficient, its average is calculated to obtain the greyrelational grade. The grey relational grade is expressed as follows equation (2)[12]:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i\,(k) \qquad (2)$$

However, in actual application the effect of each factor on the system is not exactly same; Equation 2 can be modified asequation (3):

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} w_k.\xi_i\,(k) \;\; ; \;\; \sum_{k=1}^{n} w_k = 1 \quad (3)$$

Where w_k represents the normalized weighing value of factor 'k'. Given the same weights, Equations 2 and 3 are equal.

In grey relational analysis, the grey relational grade is used to show the relationship among the sequences. If the two sequences are identical, then the value of the grey relational grade is equal to '1'. The grey relational grade also indicates the degree of influence that the comparability sequence could exert over the reference sequence.

II.2. Analysis of Variance (ANOVA)

The purpose of ANOVA is to find which individual factor and interaction between them significantly affect the multi-performance characteristics. This statistical analysis is based on the variance, the degrees of freedom, the sum of squares, the mean squares, the F-ratio, the P-value and the percentage of contribution to the total variation. It is proposed to carry out analysis of variance (ANOVA), interaction effect analysis and various model adequacy tests using the *Design Expert Software.*

II.3. Stimuli and the Experimental Task

Stimuli material should be available to the subjects in the form of a particular color through virtual colored light emitting diodes (LEDs) pan positioned on the AGV working platform. In the designed research setup, the colors used for visual stimuli were sky blue, orange, black and magenta similar to existing AGV panel color menus. As the availability of visual stimuli during the task is concerned, the LEDs 'on' and 'off' positions are controlled randomly through the LabVIEW program. A laboratory designed AGV control panel through LabVIEW with working platform is proposed to be used for the experimentation.

For experimentation, the AGV panel (designed using convertible laptop) could be joined with the load cell and the assembly could be fixed on a fabricated adjustable ‘height’ and ‘angle’ working platform [13]. The variable working distance [14] could be incorporated with the help of colored strip pasted on the ground in front of the assembled working platform. The operator’s performance measures namely search time, select time, motor action time and applied force can be recorded through LabVIEW. During the experimentation, subjects should be asked to stand in front of the working platform [15]according to the selected HCIM system parameters combination with index finger of the right hand placed (for search time) on the holding switch away from AGV panel (main menu for select time and sub menu for motor action time). The applied force may be recorded using AGV panel (both main menu and sub menu) attached with another laptop through Data Acquisition (DAQ) system (NI9234). The whole task of the experiment should be performed by the subject through his right hand index finger.

Before execution of the actual task, the subject should be trained on the simulated AGV panel. The subject during the experiment is required to respond according to the visual stimuli (ON position of a particular color LED programmed through LabVIEW). The subject respond in terms of lifting the index finger and pressing same colored designed switch on the main AGV panel menu. The time difference, between glows of light on LEDs pan and finger lift is stored as ‘search time’ and finger lift and switch pressed on main menu is stored as ‘select time’. Later, on the appearance of sub menu through LabVIEW program, the subject is required to press same colored designed switch on the sub AGV panel menu. The time difference between switch pressed, on the main menu and sub menu is stored as ‘motor action time’. For recording the applied force as a performance measure, a separate LabVIEW program may be developed. During the experimental task, the applied force, resulted through the pressing of two switches on the AGV panel main and sub menus, could be stored.

II.4. Experimental Set-Up

In this research methodology an AGV panel was simulated using a convertible laptop loaded with LabVIEW software as shown in Fig. 1. Another laptop loaded with LabVIEW, in the setup was used to record the applied force as shown in Fig. 2. The convertible laptop was fixed to an adjustable platform with load cell (piezo-electric sensor). The height and angle of the platform were adjustable according to the selected ranges.

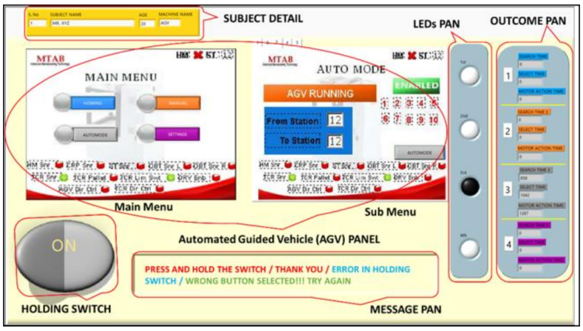

Fig. 1. Performance measurement setup with AGV panel

Fig. 2. Subject executing motor action and applied force tasks

Human performance can be measured in terms of search time, select time, motor action time and applied force through performing experiments in a simulated environment, in terms of temperature, illumination level ([16], [13]), relative humidity [13], sound level ([16], [13]) etc. The positions of the indigenously designed AGV panel, subject and other peripheral devices could be maintained as portrayed in the schematic diagram in Fig. 2. As shown in the Fig. 3, the standing subject (item 1 of Fig. 3) in front of AGV panel can maintain any working distance (40/50/60 cm) according to colored strips (as item 2 of Fig. 3). The working platform (item 2 of Fig. 3) can be adjusted at any (84/94/104 cm or else) height through adjustable screw. The AGV panel (item 4 of Fig. 3) can also be adjusted at any (170/180/190 degrees or else) angle through adjustable mechanism. Fig. 4 shows the load cells (piezoelectric sensor) arrangement, which was used to fix on mica. Finally, this structure was assembled with a self-fabricated adjustable panel, to give a shape similar to an AGV panel.

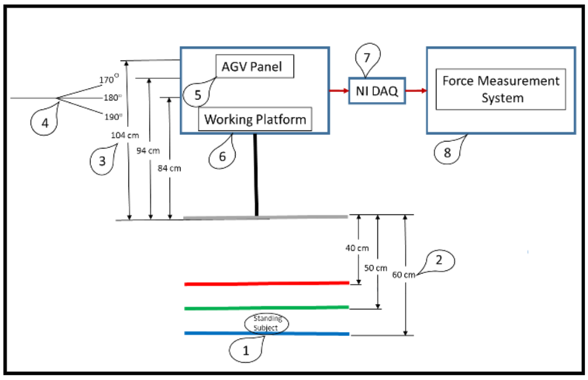

Fig. 3. Schematic diagram of the experimental set-up for experimental investigations

Fig. 4. Load cells (piezoelectric sensors) fixed on mica

III. DISCUSSION

World Health Organization (WHO) and Occupational Safety and Health Administration (OSHA) consider the cause of work related musculoskeletal diseases as multi-factorial. Management and workers in the recent scenario of automation are greatly concerned with the working environment, ergonomics, quality of work and occupational safety and health. The development in information and communication technologies and specialized work requiring repetitive task add up to a need for human-machine interface design. Ergonomists are concerned with the complex physical relationships between peoples, machines, job demands and work methods. Nowadays, major emphasis is on preventing musculoskeletal injuries in the workplace. Prevention of these injuries is accomplished by understanding biomechanics and physiology of work, through the use of biomechanical models, laboratory simulations, field studies and job analysis. Musculoskeletal disorders (MSDs) is a health disorder caused by repetitive motion, inadequate working posture, excessive exertion of strength, body contact with sharp surface, vibration, temperature, etc. MSDs can be minimized by prevention and management. Benefits for the prevention and management of MSDs show improvement of the work environment, the relation between the labor and management, productivity and decrease in lost workdays. From a long- term viewpoint, it can reduce financial losses and create the image of safe work place. MSDs are widespread and occur in all kinds of jobs. However, work related musculoskeletal disorders are not only health problems; they also are a financial burden to society. The costs are related to medical costs, decreased productivity, sick leave and chronic disability [17].

IV. CONCLUSIONS

This work has been presented an effective research methodology for the optimization of the human-AGV interface environment with multi performance characteristics. Based upon the study, following concluding points are drawn:

1. Re-evaluation of the existing CIM environment from the impact of anthropometric factors point of view is needed. It is explored that the variables AGV panel height, operator working distance and panel angle are important from the ergonomic evaluation of HCIM using AGV view point.
2. It is concluded that panel operated CIM systems in general and AGV in particular, should be redesigned so as to have an operating panel with the adjustments of both height and angle.
3. It is further observed that various ergonomic databases should be generated for the effective and efficient utilization of a CIM system. The databases should be in terms of AGV panel height, operator working distance and the panel angle.

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