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Review of Recent Developments in Ergonomic Design and Digital Human Models

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***Abstract* – The paper proposes a literature review on the workplaces ergonomic effective design in the manufacturing systems and industrial plants sector. The main objective is to provide the reader with an accurate overview on the main scientific approaches proposed (during the last decades) by researchers and scientists working in this specific area. The paper passes through the description of several research works as they run through the literature. The initial search identifies a huge number of articles which were reduced to about 50 studies based on content and quality. The descriptive analysis of the literature reveals heterogeneity in the content of the scientific approaches due to the different principles, methods and tools applied for improving the interaction between humans and their working environment.**

***Keywords*– Manufacturing systems, ergonomics, effective ergonomic design, workplaces, workstations.**

I. INTRODUCTION

The high complexity of manufacturing systems in terms of interaction between humans and their working environment continuously provides challenging problems for researchers working in this specific field. An ergonomic approach to the design of an industrial workplace (ergonomic effective design) attempts to achieve an appropriate balance between the worker capabilities and worker requirements, to optimize worker productivity, as well as provide worker physical and mental well-being, job satisfaction and safety.

During the last years this research area has became more and more important due to its effects on system efficiency and productivity. In this regards, different research works have been proposed and several scientific approaches have been developed trying to achieve the ergonomic effective design of the workplaces belonging to the manufacturing system. It is the intent of the paper to present a literature review on this specific area clustering the high quality research works according to the scientific approach they propose. In this regards, the authors identify three different scientific approaches based on different principles, methods and tools. The description of the research works for each scientific approach represents the core part of this literature review.

Before getting into the details of the study, in the sequel a brief overview of each section of the paper is presented. Section 2 describes the scientific approach based on the use of video tape systems. Section 3 presents a number of research works using several ergonomic standards for achieving the ergonomic effective design. Section 4 discusses about the third scientific approach based on the interaction between ergonomics and work measurement aspects. Section 5 presents briefly an ergonomic effective design application example based on a scientific approach proposed by the authors. Finally, the last section reports the conclusions that summarize the scientific contribution of the work.

II.VIDEO TAPE SYSTEMS FOR THE ERGONOMIC WORKPLACES DESIGN

The evaluation of the ergonomic risk levels affecting a workplace represents the first step for achieving the ergonomic effective design. In industrial plants, for existing workplaces the ergonomic risks can be assessed through observation (Karhu et al. 1981). In this context, a video tape based approach is easy and time saving (Vedder and Hellweg, 1998). In effect the interference of video camera with the tasks being performed by the observed worker is minimal. However, note that if the operations require to move to different plant areas, multiple cameras have to be used.

Neverthless, during the years a number of research works proposes the use of the video tape systems as main tool for the ergonomic effective design. Such research works are here presented as they run through the literature. Hagström et al. (1985) and Engström et al. (1987) use video recording respectively in the meat-cutting and vehicle design research areas. Das and Sengupta (1996) provide the guidelines for a good workstation design by observing workstation procedures and collecting data by video taping the operators as well (an application example is proposed in the field of supermarket checkstand

workstations). Engstrom and Medbo (1997) develop a video based observation method for time data collection and analysis of work time consumption. The method allows to measure the efficiency of the production system by separating between value-added and not value-added works activities.

Vedder (1998) presents an easy-to-use video-based posture analysis method for workplaces, where tasks interference have to be minimized and postures have to be observed over a longer period of time. The author identifies hazardous postures and their causative factors and then decides the appropriate re-design measures. The approach based on video tape systems for data collection and analysis has been also used by Kadefors et al. (2000). In this case the video film is displayed on the computer terminal for evaluating (by using an interactive procedure) workers' ergonomic problems (pain and discomfort).

Neumann et al. (2001) present a video-based posture assessment method capable of measuring trunk angles and angular velocities in industrial workplaces. Forsman et al. (2002) propose a method based on video recordings synchronized with physiological measurements for characterizing work time consumption and physical work load of manual work. The method was developed throught two casies studies within the Swedish automotive industry. It is concluded industrial interventions could be designed by means of such method. Actually the use of the video tape could generate a vast amount of recordings which are tedious to analyze. Even in this case, such scientifc approach allows to identify the tasks causing hazardous postures and suggest appropriate redesign measures as well. In this regards, Vedder and Hellweg (1998) record twenty days and nights shifts in a fibbre spinning area of a chemical plant by means of a stationary camera. A very long analysis of the videotapes allows them to provide the guidelines for a correct redesign of the system
under consideration.

III. ERGONOMIC STANDARDS

The second scientific approach regards the application of ergonomic standards as support tools for the ergonomic effective design. Among the ergonomic standards, the following have to be regarded as the most widely used: the NISOH 81 and the NIOSH 91 equations for lifting tasks (NIOSH stands for National Institute for Occupational Safety and Health); the OWAS analysis for analyzing working postures (OWAS stands for Ovako Working Analysis System); the RULA method for estimating the risks of work- related upper limb disorders (RULA stands for Rapid Upper Limb Assessment);
In the sequel research works are introduced according to the ergonomic standard used. The section consists of 5 subsections. Three subsections for presenting the research works concerning the most widely used ergonomic standards (one subsection for each ergonomic standard). The forth subsection is then reported for introducing the less used ergonomic standards: the OCRA methods for analyzing worker's exposure to tasks featuring various upper-limb injury risk factors (OCRA stands for Occupational Repetitive Action); the Garg analysis for assessing the energy expenditure for performing an operation; the Burandt- Schultetus analysis for lifting tasks involving a large number of muscles. In conclusion, the last subsection proposes the research works based on the integration of several ergonomic standards. Before getting into the details of each subsection, a brief description of the ergonomic standard under consideration is provided.

IV. ERGONOMICS AND WORK MEASUREMENT

Another important issue to take into consideration in the workplace design is the strict relation between the concepts of work measurement and ergonomics. The measurement of the work aims at evaluating the time standard for performing a particular operation. On the contrary, the concept of ergonomics is often indicated as study of work (Zandin 2001) and studies the principles that rule the interaction between humans and their working environment. In effect, the work measurement and the ergonomics affect each other: ergonomics changes affect the time required for performing the operations as well as any change to the work method affects the ergonomics of the workplace. Different research works have taken into consideration both ergonomics and work measurement aspects.

Das and Sengupta (1996) propose a workstation design procedure based on the optimization of the worker and total system productivity as well as worker physical and mental well-being, job satisfaction and safety.

Resnick and Zanotti (1997) underline that ergonomic principles can potentially be used to improve productivity as well. An application example is proposed for remarking that a workstation can be designed to maximize performance and reduce costs by considering both ergonomics and productivity together. Laring et al. (2002) develop an ergonomic complement to a modern MTM system called SAM. In particular the authors propose a tool that gives the possibility to estimate simultaneously the consumption of time in the envisaged production and the biomechanical load inherent in the planned tasks.

Udosen (2006) propose a tools for construction, evaluation and improvement (in terms of ergonomic and time issues) of a workplace for the assembly of a domestic fan. Another important issue cited in many research works developed in the last decades of the 20th century is the application of the ergonomic standards and

work measurement methods directly in the real system. Usually such approach requires a huge amount of money and time for exploring all the possibilities in terms of workstations configurations, work assignment, works methods, etc. Therefore researchers and practitioners started to develop research works by using Modelling & Simulation (M&S) as support tool for choosing correctly, for understanding why, for diagnose problems and explore possibilities (Banks, 1998). From an animation point of view, the simulation provides virtual three-dimensional environments that strongly support the workstation ergonomic design. A three- dimensional visualization is certainly an important support that can be used to detect problems and critical factors that otherwise would be difficult to detect.

Wilson (1997) proposes an overview on attributes and capabilities of virtual environments (devoted to support ergonomic design) and describes a framework for their specification, development and evaluation.

Marcos et al. (2006) aim at reducing the stress of the medical staff during laparoscopic operations simultaneously increasing the safety and efficiency of an integrated operation room. To this end, the authors develop a simulator by integrating the CAD software (CATIA) and the simulation software (RAMSIS). Over the years the M&S approach has became more and more appealing thanks to the numerous advantages such as the possibility to study ergonomic issues at the earliest stages of design in order to avoid potential future ergonomic redesign in the real-world system.

Feyen et al. (2000) propose a PC-based software program (based on the integration of a Three- Dimensional Static Strength Prediction Program, 3DSSPP, for biomechanical analysis with a widely used computer-aided design software package, AutoCAD). As consequence, the authors are able to study ergonomic issues during the design phase taking into consideration different design alternatives.

Chang and Wang (2007) propose a method for conducting workplace ergonomic evaluations and re- design in a digital environment with the aim of preventing work-related musculoskeletal disorders during assembly tasks in the automotive sector.

Longo et al. (2006) use M&S in combination with ergonomic standards and work measurement for the effective design of an assembly line still not in existence. The authors propose a multi-measures approach with the aim of obtaining a different work assignment to each workstation, better line-balancing and better ergonomic solutions.
Santos et al. (2007) propose an ergonomic study on working positions in a manufacturing company (by using the simulation software eM-Workplace) and providing, as result, remarkable ergonomic improvements. In particular, the study is based on the integration of several ergonomic standards (NIOSH 81, NIOSH 91, Burandt Schultetus, OWAS and Garg analysis) and the Method Time Measurements (MTM) methodology.

V. APPLICATION EXAMPLE

The authors propose their scientific approach for the ergonomic effective design by means of a real case study. The case study regards the most critical workstation (the Seal Press workstation) of a manufacturing process devoted to produce high- pressure hydraulic hoses. The effective ergonomic design of the workstation takes into consideration both ergonomic risks and work measurement. The actual workstation configuration is compared with several alternative scenarios by using a well planned experimental design. To this end, the authors propose an approach based on multiple design parameters and multiple performance measures with the aim of considering both the interaction of the operators with their working environment and the work methods. In addition, the authors use Modelling & Simulation (M&S) as a support tool for implementing a three- dimensional environment capable of recreating, with satisfactory accuracy, the real Seal Press Workstation.

1. Simulation model development

The first step was the development of a simulation model capable of recreating the production process of the workstation. The simulation model development involves three different phases: collecting data concerning the Assembly area (data collection phase), reproducing the real system in the virtual environment from both a geometric and work method point of view (simulation modelling phase) and verifying if the simulation model is an accurate representation of the real system (validation phase). Figure 1 shows a panoramic view of the virtual layout of the Seal Press Workstation.

Fig.1. Simulation model of the Seal Press workstation

2. Design of Experiment

A well-planned Design of Experiments (DOE) is used for supporting the comparison of the actual configuration of

the Seal Press workstation with alternative operative scenarios (different workstation configurations). The DOE requires to select a set of design parameters (a group of factors to be changed during the simulation runs). We take into consideration the following factors:

- Support table angle: let us indicate this angle with α, it defines the orientation of the support table respect to the actual position (see figure 2);
- Raw materials bin height: let us indicate this height with rmh, it defines the height of the bin containing the raw materials (see figure 2);
- Ring nuts bin height: let us indicate this height with rnh, it defines the height of the bin containing ring nuts exiting from the seal press machine (see figure 2).

Fig.2. Actual configuration of the Seal Press workstation (with design parameters).

Note that the figure 2 shows the actual configuration of the Seal Press workstation.
Table 1 reports factors and levels; the factors levels combinations create a comprehensive set of different scenarios in terms of workstation layout and tools disposition (8 different configurations to be tested with the simulation model).

Table 1 Design parameters and levels

Seal Press Workstation				
Factors	Factor ID	Level 1	Level 2	
Support Table Angle	a	0	p/2	rad
Raw Materials bin height	rmh	17	86	cm
Rings nuts bin height	rnh	30	65	cm

As previously stated, the effective ergonomic design of a workstation consider a multi-measures approach based on ergonomic and work measurement indexes. The ergonomic performance measures, based on ergonomic standards, are the lift index (evaluated by using the Burandt- Schultetus analysis), the stress level associated to each working posture (evaluated by using the OWAS analysis) and the energy expenditure associated to each activity (evaluated by using the Garg analysis). The most important performance measure for work measurement is the process time; we use the Method and Time Measurement methodology (MTM-1) for evaluating the process time.

3. Simulation results and workstation final configuration

The experiments before described (8 different configurations to be tested with the simulation model) have been completely carried out by using the simulation model, monitoring for each alternative scenario the multiple performance measures. Table 3 reports the simulation results. The authors analyze the effects of each design parameter on the performance measures and according to such analysis develop a new work station configuration. Figure 3 shows the effective ergonomic re-design of the Seal Press workstation (final design).

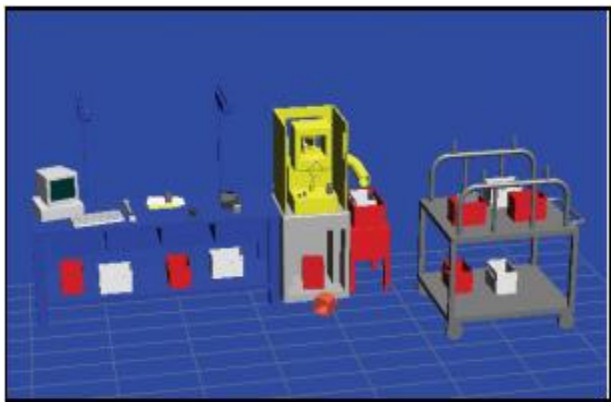

Fig.3. Effective ergonomic design of the Seal Press workstation.

Further research works on workstation ergonomics effective design using Modeling & Simulation combined with ergonomic standards and work measurement can be found in Longo et al. (2005), Longo et al. (2006-a), Longo et al. (2006-b), De Sensi et al. (2007-a), De Sensi et al. (2007-b), Bocca and Longo (2008).

Table 3 Simulation results

Seal Press Workstation							
a	rmh	rnh	Burandt-Schultetus		OWAS	Garg	MT M-1
			Permissible Force (N)	Actual Force (N)	Stress Level	Energy Expenditure (Kcal)	Process Time (sec)
0	17	30	121.3	147.2	3	1480.0	470.32
0	17	65	135.0	147.2	2	1438.8	464.75
0	86	30	137.7	147.2	2	1403.6	460.23
0	86	65	151.4	147.2	1	1362.4	454.66
p/2	17	30	121.3	147.2	3	1439.4	456.71
p/2	17	65	135.0	147.2	2	1398.3	451.14
p/2	86	30	137.7	147.2	2	1363.0	446.62
p/2	86	65	151.4	147.2	1	1321.9	441.05

VI .CONCLUSIONS

The main objective of the paper is to present a literature review concerning the ergonomic effective design. The initial search identifies a huge number of articles which were reduced to about 50 studies based on content and quality. The research works were clustered according to the scientific approach they propose. In this regards, the authors identify three different scientific approaches based on different principles, methods and tools. Several authors propose an approach based on the use of video tape systems for evaluating the ergonomic risks affecting the workplaces. Note that such evaluation represents the first step for achieving an ergonomic effective design. A number of research works propose the application of ergonomic standards. The review identifies NISOH 81, NIOSH 91, OWAS and RULA as the most widely used ergonomic standards.

The third scientific approach regards the interaction between ergonomics and work measurement aspects. In this regards, the authors identify two different thought tendencies: (i) the application of ergonomic standards and work measurement methods directly in the real system; (ii) the application of ergonomic standards and work measurement methods by means of Modelling & Simulation (M&S) as support tool for the ergonomic effective design. Finally, the literature review is completed with a scientific approach proposed by the authors for achieving the ergonomic effective design of workplaces. Note that such scientific approach is explained by means of an application example.

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