International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:13, No:10, 2019

Investigating the Effect of VR, Time Study and Ergonomics on the Design of Industrial Workstations

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Abstract**—**This paper presents the review of the studies on the ergonomics, virtual reality, and work measurement (time study) at the industrial workstations because each of these three individual techniques can be used to improve the design of workstations and task position. The objective of this paper is to give an overall literature review that if there is any relation between these three different techniques. Therefore, it is so important to review the scientific studies to find a better and effective way for improving design of workstations. On the other hand, manufacturers found that instead of using one of the approaches, utilizing the combination of these individual techniques are more effective to reduce the cost and production time.

Keywords**—**Ergonomics, time study, virtual reality, workplace.

I. Introduction

RECENTLY, apart from being classified in terms of size, product or services, the companies must strive to surpass from other rival firms [1]. In such competition there are three valuable assets that each enterprise could manage better and surpass the competitors. These three factors are; time, cost, and human force. Also, these three factors contribute directly to efficiency and profit. Therefore, if the companies could decrease the time and cost for production, transportation, maintenance together with using the human capital most effectively, these could decrease the Work-related Musculoskeletal Disorders (WMSD) on the shop floor. Thus, they need several equipment to evaluate these factors. There are three powerful methods to evaluate and design workstation in order to improve time, cost, and human force. These methods are Ergonomics, Time Study, and Virtual Reality.

Ergonomics is an application of scientific techniques, principles, and data drawn in which people play an important role for developing of engineering systems [2]. Ergonomics evaluate the posture of labors in different position in vary task job in order to improve the position of tools, motion of workers in order to increase productivity and decrease the fatigue, time production, cost, and WMSD [3], [4].

Time study or work measurement has been known as a systematic method for determining the standard time to perform a specific task for the aims of (1) developing and preferring the lowest cost system and method; (2) standardizing this method and system; (3) determining the time requirement for doing a specific task or operation by a properly trained person to do at a normal pace; (4) assisting in training the worker in the preferred method [5].

Virtual Reality (VR) is used as a tool for evaluating the dynamic and static behavior of manufacture system with provides a framework to represent a facility layout in 3D [6]. VR technology can be utilized for different purposes such as improving the design of the layouts of existing workstation [7][8], or analyzing assembly processes or single cells [9].

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II. Ergonomics

Work design is a new field of science that has the objective of outlining an arrangement in the workplace to fit it better to the human administrators in order to boost the organization productivity. In the United States, it is commonly known as human factors, while internationally it is called ergonomics, which is gotten from the Greek words for work (erg) and laws (nomos) [10].

There are many different definitions in the scientific literature such as definition from Ergo Web Inc.: "Ergonomics removes barriers to quality, productivity, and safe human performance in human-machine systems by fitting products, equipment, tools, systems, tasks, jobs, and environments to people." [11]. There are many definitions like above citation; that mention the basic principle in ergonomics is to "design the task and tools to fit the person, rather than making the person to adjust himself to the task or tools" [12]-[14].

As shown in Fig. 1, the internal ergonomic assosiation divides ergonomic to the three sections which are known as Cognitive Ergonomics, Organization Ergonomics and Physical Ergonomics [15], [16].

A. Cognitive Ergonomics

The cognitive ergonomics is a branch of ergonomics that studies the mental processes such as memory, perception, motor response, and reasoning as they affect the humans and other parts of a system and their interaction among each other. The topics that are relevant to cognitive ergonomics are human reliability, decision-making, mental workload, human-computer interaction, work stress, skilled performance and training as these may relate to human-system design [15], [16].

B. Organizational Ergonomics

Organizational ergonomics is a branch of ergonomics which is concerned with the optimization of systems. The subjects that are studied in organizational ergonomics include: communication, teamwork, work design, telework, virtual organization, cooperative work, community ergonomics and quality management [15], [16].

C. Physical Ergonomics

Physical ergonomics studies the physical and physiological stresses and the response of the human body to them. It needs several characteristics of the human like physiology, anatomy, biomechanics and all other fields that are related to physical activities. When the ergonomic principles are ignored in the shop floor, it is certain that musculoskeletal disorders (MSD) are a potential outcome; and it is not an appropriate event for the enterprise, so, one of the objectives of physical ergonomics is the reduction of MSD-risk or decrease in worker's compensation cost. The other benefits of physical ergonomics are increased productivity, reduced turnover and absenteeism, improved quality, improved efficiency, improved employee morale and reduced downtime [15], [16].

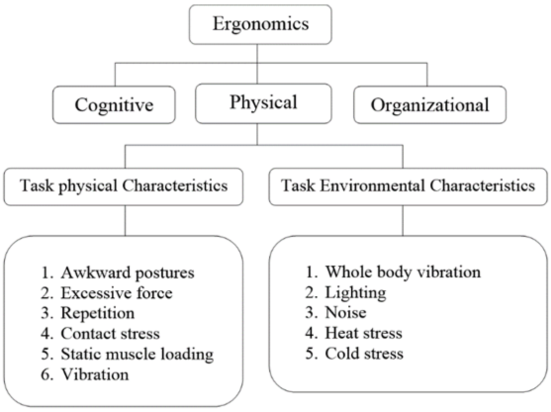

Fig. 1 Division of internal ergonomic association

III. Ergonomic Measurement Methods

Currently, there are four methods available for applying the scoring technique in order to evaluate MSD that are shown in Fig. 2. These techniques are pen-paper based observational methods, observational methods based on computer or video tape, direct/instrumental methods, self-reporting method [17]-[20].

A. Pen-Paper Based Observational Methods

The pen-paper based observational methods were developed in the early 17th century by Priel's method. This kind of ergonomic measurement methods records the posture based on pen-paper, before that the posture was recorded with drawings and photographs [17], [21], [22]. Various pen-paper based methods are categorized in Table I.

B. Observational Methods Based on Computer or Video Tape

This method records the postures, workstation positions, and tasks by computer or video recordings, and analyses them with computers. In these methods, the observation is based on time sampling and real-time simulation. Table II shows categorizing of this method [23].

For recording and motion analysis, there are several commercial systems that record body movement and posture in 2 or 3 dimensional plane as some of the important and common ones are mentioned as:

- PEAK Motus System [24]
- VICON System [25]
- Kinemetrix 2D/3D Motion Analysis Systems [26]
- SIMI Motion System (Reality Motion Systems) [27]
- APAS (Ariel Performance Analysis System) [28]

C. Direct/Instrumental Methods

Body posture can be illustrated by using a direct method manually or continuously. The manual method uses hand-held devices and continuous method uses electrical instruments. In the manual method, in order to measure the angles of the body segments, the device is attached to the body section and draws a trace on paper (flexi-curve) or indicates on the device (inclinometer). With electrical instrumental methods, an electrical output signal is generated proportional to the intersegment displacement [18], [29].

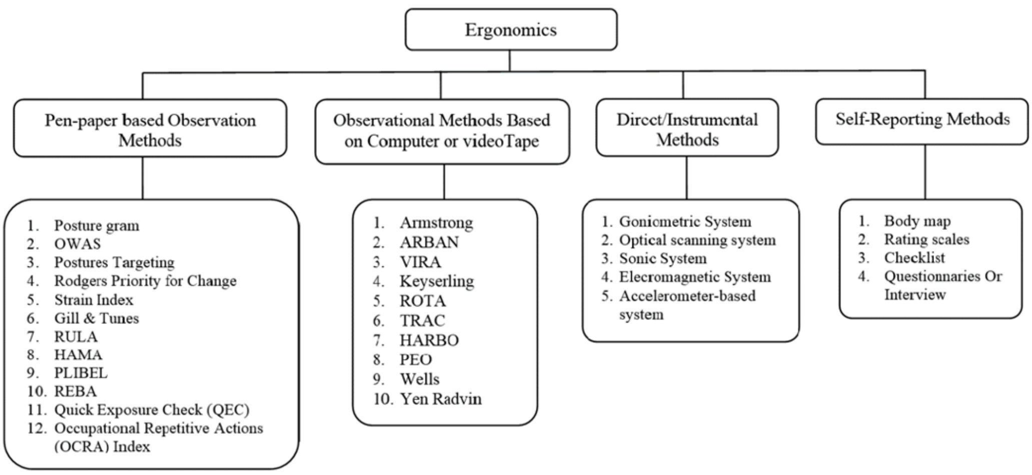

Fig. 2 Various Ergonomic Measurement Methods

TABLE I
VARIOUS PEN-AND-PAPER-BASED OBSERVATIONAL TECHNIQUES

Applications	Techniques	Developer	Basic features
Evaluation of the whole body posture for static tasks	Posturegram [33]	Priel (1974)	Body postures are recorded and categorized as digital numbers by time sampling.
Analysis of the whole body posture	Ovako Working Posture Assessment. System (OWAS) [34]	Karhu et al. (1977)	Categorizes body position with digital numbers
Evaluation of the whole body posture for static tasks	Posture Targeting [33]	Corlett et al. (1979)	Body postures are identified by angles and directions together by time sampling
Evaluation of the whole body posture for static and dynamic tasks	Rodgers Priority for Change [35]	Suzanne Rodgers (1988)	Categorizes body posture risk by evaluation in three factor levels
Evaluation of the whole body posture for seated tasks	Gill & Tunes [18, 33]	(1989)	Categorizes body posture with angles and frequency of occurrence.
Upper limb assessment	Rapid Upper Limb Assessment (RULA) [18], [36]-[43]	McAtamney and Corlett (1993)	Categorizes body posture with numbers that are computed for force and muscle activities.
Upper limb assessment	Hand-Arm-Movement Analysis (HAMA) [18]	Christmansson (1994)	Records the kinds of motion, load handled, hand position and grasps; the data and work activities are linked to each other.
Classification of risk factors	Plan för Identifiering av Belastningsfaktorer (PLIBEL) [18]	Kemmlert and Kilbom (1987), Kemmlert (1995)	Checklist with several questions about different body posture.
Evaluation of the upper limb MSDs for repetitive activities	Strain index [44]	J. Steven Moore Arun Garg (1995)	Evaluate body posture with strain index that estimates several factors like force, time, body position and etc.
Evaluation of the whole body for the risk assessment in 'non-sedentary' tasks	Rapid Entire Body Assessment (REBA) [18], [43], [45]	McAtamney and Hignett (1995)	Scores the body position and load according to action levels.
Evaluation of the body posture for static and dynamic tasks	Quick Exposure Checklist (QEC) [18]	Li and Buckle (1998)	Evaluates the body posture and assigns a score to the repetition activities and force/load from a special score table.
Evaluation of the upper limb for static or dynamic Repetitive activities	Occupational Repetitive Action (OCRA) [46]	E. Occhipinti (1998)	Analyses and evaluates risk factors, force/load, body posture and time sample

TABLE II
DIFFERENT COMPUTER-AIDED AND VIDEOTAPING OBSERVATIONAL METHODS

Applications	Techniques	Developer	Basic features
Upper limb assessment	Armstrong [18]	Armstrong et al. (1982), Armstrong (1986)	Computerized data and time sampling video for posture and force; indicated hand position as several kinds of pinch or grasp; contact area with finger or hand as coded numbers.
Assess physical stress in whole body	ARBAN [18]	Holzmann (1982)	Computerized analysis; Code load situations and postures by time-sampling; used Borg's scale for estimation of the muscle stress, posture effort and vibration.
Upper limb assessment	Video Registration and Analysis (VIRA) [18]	Persson and Kilbom (1983), Kilbom et al. (1986)	Computerized real-time analysis for duration and frequency of postures and motion.
Evaluation of the repetitive and non-sedentary tasks	Keyserling [18]	Keyserling (1986)	Computerized real-time analysis for duration and frequency of body position in predefined body position categories.
Dynamic or Static tasks	ROTA [47]	Ridd et al. (1989)	Computerized time Sampling or real time analysis on different posture and activity.
Dynamic or Static tasks	Task Recording and Analysis on Computer (TRAC) [48]	van der Beek et al. (1992)	Computerized real-time analysis or time sampling on different posture and activity.
Long observation for various types of tasks	Hands Relative to the Body (HARBO) [49]	Wiktorin et al. (1995)	Computerized real-time data from work postures; Identifying the position of hands at three levels.
Analyze Trunk and Upper limb posture for dynamic tasks and manual handling	Portable Ergonomic Observation (PEO) [50]	Fransson-Hall et al. (1995)	Computerized the data that are collected in real-time on work activity and posture movement.
Upper limbs and low back physical exposure assessment	Wells [18]	Wells et al. (1994)	Computerized data analysis on repetition, EMG signals, synchronized posture and activity.
Evaluation of the repetitive and arbitrary activities	Yen and Radwin [18]	Yen and Radwin (1995)	Synchronized video images with analogue data recording.

D. Self-Reporting Method

This method is used to assess the physical load force, work stress or body discomfort by collecting the data on physical and psychosocial factors on the workstation through paper questionnaires, interviews and worker diaries [30], [31] or use of web base questionnaires [31], [32].

IV. TIME STUDY

Time study is one of the oldest key systems ever utilized to increase productivity. So the time study is used as an important tool in manufacturing industry for analysing and developing methods for evaluation of the employees. It is used to create employee productivity standards through the broken a complex task into simple and small steps, measuring precise time for each correct movement and detecting the wasteful motion in the task sequence [5]. According to Meyers method, the time study is about the time of producing a product in a workplace with three conditions. These conditions are a qualified operator, working at a normal pace and doing a particular task. Therefore, the time study is the time, that is determined by a qualified and prepared operator working at a normal pace to do a particular task [5], [51].

Time study has many principle and objectives with considering different aspects of production. The first objective is minimizing the time that is necessary for doing a task. The second objective is making balance between the work of the workers and the product. The last objective is increasing the well-being, health and safety of all human resources an environment. There are several different methods for time study while many of them utilize the same techniques in their study. Table III shows the five different time study techniques.

TABLE III
VARIOUS TIME STUDY TECHNIQUES [51]

No.	Source	Technique
1	Barnes (1980) [5]	• Standard Data • Work Sampling • Predetermined Time Standard System (PTSS) • Stopwatch Time Study
2	Laring (2002) [60]	• Time Study • Standard Data Systems • Predetermined Time Standard Systems (PTSS) • Work Sampling • Physiological Work Measurement • Labour Reporting
3	Niebel and Freivalds (2008) [10]	• Time Study • Standard Data and Formulas • Predetermine Time Standard Systems • Work Sampling • Indirect and Expense Labour Standards

V. VR

VR is described as "a 3-D environment, computer-synthesized, appropriately interfaced, and might manipulate and engage simulated physical component in the 3-D environment". So VR can be illustrated as a 3-D artificial environment that is created with computer programming in order to simulate an environment that is acceptable by the users. The goal of VR is to make a perception and view of a real environment with utilization of multi-media that allows the users to experience and evaluate the different scenarios with low cost and time [52], [53].

Virtual manufacturing (VM) is an virtual manufacturing environment which is utilized to increase the ability of enterprises to make the optimum decisions. VM simulates a model of manufacturing levels with the same parameters and takes all that information to the process, process management and control, and data product [54], [55].

VI. LITERATURE REVIEW

In this research, a review of the related research works that are performed in the area of Ergonomics, VR and Time Study and their combination for different purposes is presented below.

Ulin et al. studied designing workstation, manipulate manikins and shop floor components with using macros. In their research AutoCAD software package was utlizied for simulation, and manipulating manikins, analyzing jobs, and parametric designs was used for drawing work equipment by macros [56].

Das and Sengupta proposed a procedure for designing workstation based on the optimization of the ergonomics of the labor, safety, job satisfaction, total system productivity, and worker mental and physical well-being [57].

Feyen et al. offered PC-based software that allows the designers to evaluate the proposed workstation design in order to measure the biomechanical risk. The program was composed of a software tool for biomechanical analysis, the Three-Dimensional Static Strength Prediction Program (3DSSPP), with a broadly used AutoCAD as a CAD software package. The software allows the authors to research and study about ergonomic stuffs through designing workstation phases with taking into consideration different designs. The authors described the use of this 3DSSPP/AutoCAD interface in the analysis of an automotive assembly task and compared the results with the data that were taken from a direct independent assessment of the same task [58].

Sang et al. studied initial efforts of simulation as an analysis tool and a visual management at an automotive engine block foundry plant. In their research Pro Model software was used to model the foundry process for evaluating machine performance, bottleneck, production data, and cycle times (total parts, throughput, rejects, products) necessary for efficient production control. By changing the number and processing time of assembly machines different scenarios can be created which can be utilized to find the optimum number of assembly machines [59].

Laring et al. developed an ergonomics complement to a modern Methods-Time Measurement (MTM) system called SAM. This research proposed a tool with ErgoMOST software for estimating the biomechanical force inherent in the planned tasks and time consumption in production [60].

Jayaram et al. suggested two different approaches to link Virtual Environment (VE) and quantitative ergonomic analysis tools in real time to study about industrial ergonomics. The first approach aims to create methods for integrating the VE with commercially available ergonomic analysis tools, while the second approach aims to create an ergonomic analysis module that is built-in to a VE. The authors described the two strategies and tested them in a real industrial company as a case study [61].

Udosen proposed a technique utiliznig CADWORK, time study and ergonomics conseots for construction, evaluation, and improvement of a domestic workstation for assembly fan [62].

Longo et al. studied about combination of Modelling & Simulation (M&S) with work measurement and ergonomic standards for designing an assembly line before construction. The aims of their research were to obtain a different work assignment to each workstation, better ergonomic solutions, and better line-balancing [63].

Francesco et al. offered an assembly line for product heaters. This research studied the effects of the design of an assembly line workplace with integration of the simulation and modelling with ergonomic analyses [63].

Shao-Wen et al. used virtual dynamic simulation workstation and digital human modelling for evaluating WMSDs in automobile assembly tasks. This research used RULA system in DELMIA software to improve ergonomic tools in automobile workstation [39].

Chang and Wang proposed a method for redesigning and evaluating ergonomics at workstation in VE with the purpose of reducing and preventing WMSDs during assembly process in the automotive sector [39].

Santos et al. studied task positions in a manufacturing system ergonomically by using eM-Workplace as a simulation software and provided remarkable ergonomic improvements. This research used several ergonomic standards (OWAS, Burandt Schultetus, NIOSH 91, Garg analysis, and NIOSH 81) and MTM methodology [64].

Cimino et al. proposed an approach based on the integration of several ergonomic standards, simulation & Modelling tools, and the work measurement tools. This research used the ergonomic standards for evaluating the ergonomic risk level, and simulate real workplace in VE by simulation and modelling tools, and also, calculating time requirement to carry out all the operations by work measurement tools [65].

Vaclav et al. studied and suggested a method for designing a manual assembly workspace in a CAD environment. Their method was intended to create good work conditions to achieve productivity and high quality of work. They used the CATIA ergonomic modules for analysing and designing efficient solutions to optimize the layout of manual workstations [66].

Garbie did an experimental study about smart adjustable workstation on ten persons in three experimental conditions (gender, chair adjustable and table adjustable) working on an assembly of an electrical switch that consisted of 8 parts and used Minitab Statistical Software Package to analyse the results. This research studied how to measure the rate of production in manual assembly lines in assembly workstations that are ergonomically designed [67].

Saptari et al. studied about the effect of jig design, assembly design, workplace design and posture of worker on the time assembly of plugs. This research showed that these factors were significant. However, the interaction combinations of these factors were not important at assembly time. Meanwhile, this research used RULA method for evaluating working posture, and found a position that take the lowest RULA score which is safe [41].

Grajewski et al. evaluated the possibility of using the haptic technologies and immersive VR in the complex process of design of the manufacturing workstation with high level of ergonomic quality. This research studied using haptic devices with force feedback effect to study welding in workplace, and using Head-Mounted Device, to improve ergonomics of the manual assembly and hole drilling in workplace. Eventually, it can be concluded that utilizing a combination of virtual techniques is one of the best methods to design a workstation [68].

Arun et al. studied the human factors and work methods for the assembly mono block pump by simulating workplace in CATIA and Pro-E software and analyse with RULA method for identifying WMSDs. In their study, they proposed several methods like use of hydraulic press, screw gun and an automatic conveyor for improvement tasks [42].

Pontonnier et al. evaluated a part of the VISIONAIR European Project in ergonomics applications based on VR. This research studied about the capability of CVEs as a valuable tools for ergonomics, and had shown the relative and difference between real and VE in workstation [69].

Mahatme et al. evaluated workstation design and ergonomic analysis for sheet metal disc, teeth cutting operation on a power press. In their research, the ergonomic details were studied by REBA and RULA methods. This research used CATIA software for simulating and CAD modelling for RULA analysis and used REBA assessment worksheet for REBA analysis [70].

Kunz et al. proposed a novel VR-based MTM for evaluating manual operations. This method could simulate real walking in virtual factories without using walking devices like treadmill, and could create a movement space in virtual factory larger than the available physical space [71].

Zhou et al. proposed a corrective MOD method to predict the maintenance time by using ergonomic factors in DELMIA software as the simulation and analysis tool. This research studies the virtual prototype of APU motor starter as the case study [72].

VII. Discussion

The above researches are classified in Table IV according to the methods that those researches used for analysing or designing task process and manufacturing workstation. According to this classification, most of the researches use VR as a tool for simulating, and the other two techniques (Ergonomics and Time Study) for analysing. Most of the researchers studied different tasks ergonomically by using VR. This shows that using these two techniques with each other are not common and it is a new area in manufacturing process. Another relationship that is not very common according to Table IV, is relationship between Time Study and Ergonomics techniques. But very important thing to conclude from this review is the relationship between these three technique for designing and evaluating manufacturing workstations. It shows that investigations have used gradually these three techniques simultaneously since 2000.

VIII. Conclusion

This study focused on the relation between three important methods (Ergonomics, Time Study and VR) in designing manufacturing system. Through the review, it can be concluded that in manufacturing process, utilizing VR and time study to simulate and analyse in ergonomics is an effective technique to reduce the production costs and time.

A significant sequel from this review is that, the relationship between these three techniques for designing and evaluating manufacturing workstations could be used as an effective tool for analysing different task process in manufacturing system.

TABLE IV
LITERATURE REVIEW SUMMARY

Method	Author and date
Ergonomics	Ulin et al. [56], Das and Sengupta [57], Feyen et al. [58], Laring et al. [60], Jayaram et al. [61], Udosen [62], Longo et al. [63], Shao-Wen et al. [39], Cimino et al. [65], R. Arun et al. [42], C. Pontonnier et. al. [69], Mahatme, et al. [70], Dong Zhou et al. [72]
Time Study	Das and Sengupta et al. [57], Laring et al. [60], Udosen [62], Santos et al. [64], Cimino et al. [65], Adi Saptari et al. [41], Andreas Kunz et al. [71]
VR	Ulin et al. [56], Feyen et al. [58], D. Sang et al. [59], Jayaram et al. [61], Shao-Wen et al. [39], S. Vaclav et al. [66], D. Grajewski et al. [68], Mahatme, et al. [70], Andreas Kunz et al. [71]
Ergo & VR	Ulin et al. [56], Feyen et al. [58], Jayaram et al. [61], Shao-Wen et al. [39], S. Vaclav et al. [66], D. Grajewski et al. [68], R. Arun et al. [42], C. Pontonnier et. al. [69], Mahatme, et al. [70]
Time Study & Ergonomics	Das and Sengupta [57], Ibrahim H. Garbie [61], Adi Saptari et al. [41]
Time Study & VR	D. Sang et al. [59], Andreas Kunz et al. [71]
Ergonomics, Time Study & VR	Laring et al. [60], Udosen [62], Longo et al. [63], Santos et al. [64], Cimino et al. [65], Dong Zhou et al. [72]

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