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Multi-Response Research Methodology for Ergonomic Design of Human-CNC Machine Interface

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Abstract
This work is aimed at enriching a research theme, focused on exploiting the performance in a human-CNC machine interface (HCMI) environment. A salient contribution of this research effort is focused on adopting the concept of load cell for the system of human-performance measurement. The developed novel system is capable of measuring cognitive and motor action responses simultaneously. The performance measurement system designed for this work may be replicated for other fields where systems are operated through control panels and also where responses of mentally retarded human-beings (or the human beings with the symptoms of Alzheimer disease) are to be observed and evaluated.
Research relevance: The research methodology designed in this work can be directly applied to the practical field to evaluate the performance in various human- panel operated system interface environments. This work suggests that those responsible for the function and operation of CNC-machines workstations would have to redesign the system to reduce injuries, as far as musculoskeletal and other related problems are concerned. The present work can be quite useful for the system designers of tomorrow.
Keywords*:* Multi-performance; Search time; Motor action time; Applied force; Load cell; CNC-Environment.

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. This would decrease the money paid out in workers' compensation. For example, over five million workers sustain overextension injuries per year. Through ergonomics, workplaces can be designed so that workers do not have to overextend themselves and the manufacturing industry could save billions in workers' compensation. Companies once thought that there was a bottom-line tradeoff between safety and efficiency. Now they embrace ergonomics because they have learned that designing a safe work environment can also result in greater efficiency and productivity. Recently, U.S. laws requiring a safe work environment have stimulated great interest in Ergonomics- from ergonomic furniture to ergonomic training. But it is in the design of the workplace as a whole where the greatest impact can be seen for both safety and efficiency. The easier it is to do a job, the more likely it is to see gains in productivity due to greater efficiency. Analogously, the safer it is to do a job, the more likely it is to see gains in productivity due to reduced time-off for injury. Ergonomics can address both of these issues concurrently by maximizing the workspace and equipment needed to do a job.

Ergonomists play an important role in evolving an optimal design of human-machine systems. Each phase of the system development introduces behavioral questions that must be answered if the system is to be designed properly (Meister, 1982). *Among the varieties of human-machine systems, Human-CNC Machine-Interface (HCMI) 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 CNC machines.*

From the preceding discussion on the role of *'Ergonomics'*, three overriding but interrelated questions emerge:

- Why should the human-CNC machine interface be designed?
- How should the human-CNC machine interface be designed?
- How the ergonomic design affects performance of the human beings*?*

1.1 Human-CNC Machine Interface Design-Why?

In order to answer the question *why should the human-CNC machine interface be designed? ,* it may be pertinent to recall briefly the main stylized facts about the musculoskeletal disorders first. In general many of the injuries in manufacturing are musculoskeletal disorders caused by cumulative trauma. We call these injuries that result from cumulative wear and tear, cumulative trauma disorders (CTDs). Back injuries, tendinitis and carpal tunnel syndrome are examples of common CTDs. Workplace risk factors for CTDs include repetitive motions, high forces, awkward postures and vibration exposure. CTDs in manufacturing can be associated with such activities as manual material handling, hand tool usage, awkward postures and prolonged equipment operation. One effective way to reduce the risk of CTDs such as carpal tunnel syndrome and back injuries is to establish an ergonomics process. Musculoskeletal disorders (MSDs) are one of the expressions used for pain in different body parts or diagnosed diseases of musculoskeletal system. It denotes health problems of the locomotors apparatus i.e. muscles, tendons, the skeleton, cartilage, the vascular system, ligaments and nerves (Danuta, 2010). The symptoms of MSDs may vary from discomfort and pain to decreased body function and invalidity. The other terms which represent MSDs are cumulative trauma disorders (CTDs), repetitive strain injuries (RSI) or work related upper limb disorders (WRULDs). Work related musculoskeletal disorders (WMSDs) can be defined as impairments of the body structures, which are caused or aggravated primarily by the performance of work and the effects of the immediate environment in which work is carried out. MSDs are widespread and occur in all kinds of jobs. According to a European survey up to 25% of workers reported back pain and 23% muscular pain (Danuta, 2010). Certain studies estimate the cost of WMSDs at between 0.5% and 2% of the Gross National Product. National and European Union surveys identify MSDs as being responsible for a large proportion of the working days lost due to illness (Danuta, 2010). About 0.8% of the European workers suffer from working conditions which cause 14 days or more of absence from work due to MSDs during the period of a year. Higher absenteeism occurs in women population than among men workers. The highest number of days out of work is among population between 40 to 54 years old (Danuta, 2010).

Nowadays, efforts in health promotion programs have increased. Notwithstanding, work related musculoskeletal disorders (WMSDs) remain a widespread and growing issue of concern in the automated manufacturing industry. In the coming years, WMSDs leading to absence and reduced employment ability along with an aging work force with comparatively high wages will become an even greater challenge to these automated manufacturing companies facing worldwide competition. The prevention of WMSDs is achieved through improvements in the design of working conditions and tasks as well as through influencing the health promoting behavior of individuals. *What is needed, nowadays, is a systematic approach, that enables automated industries to identify and control physical stress at work that leads to WMSDs in a comprehensive manner.*

1.2 Human-CNC Machine Interface Design-How?

Ever since the industrial revolution opened the vistas of a new age, the process of industrialization has been at the core of the economic development of all countries. In a simple sense, industrialization means replacement of human labor by machinery to manufacture goods. In this way it induces a shift from home (craft) to factory based production. In a more rational sense, it is a process whereby the share of industry in general and manufacturing in particular, in total economic activities increases.

Worldwide the machine tool industry is a small manufacturing sector, but widely regarded as a strategic industry as it improves overall industrial productivity through supplying embodied technology. The introduction of CNC has rejuvenated the market. The production and trade have been mostly concentrated in industrialized countries accounting for more than two-thirds of share. However, it is gaining importance among developing countries. The production of high-end machines is concentrated in the USA, Germany, Switzerland and Japan. In the mid-range segment, Japan is the market leader. In the low-end segment Taiwan and Korea are predominant. Servomechanism theories and the use of electric circuits, basically have to automate many industries, especially those which involve mass production of the same products (Groover, 1987). The desire of automation is mainly because of the least labor costs involved. It is a known fact that the automated industries which uses programmable controllers, require operator's oversight for example in fully automated production unit where the assembly line is attended by the robot, operators will be providing oversight in the events of conveyor jams or uncontrollable breakdowns. This highly sophisticated automation requires skilled programmer to maintain and innovate the technologies. *It is because of mainly above mentioned reasons that the ergonomists will play a key role as far as the better design of human-CNC machine interaction environment is concerned.*

1.3 Interface Design for CNC Machine Tool Industry

Recent developments in the field of information and communication technologies and specialized work requiring repetitive tasks have resulted in the need for a human factor engineering approach. Through examining, designing, testing and evaluating the workplace and how people interact in it, human factor engineering can create a productive, safe and satisfying work environment. With the high technology applications getting more widespread at the global level, the problems associated with the introduction of this hi-tech have also been generating more concern. Most part of such concern is reflected in occupational stresses in the form of poor job performance, waste leisure time, low level of job satisfaction, alcohol related problems and hence forth. One most notable component of hi-tech era emerged in the shape of human-CNC machine interaction that basically comprises of a CNC workstation and an operator. The use of CNC systems is increasing exponentially. This is accompanied with a proportionate increase in occupational stresses too in human operators. Previous studies relating to HCMI by different researchers in the field revealed that all sorts of problems associated with the use of CNC machines could be traced in terms of physical characteristics of the CNC workstation, visual factors, psychological factors and postural factors. Present studies are mainly associated with the last said factor that relates to constrained postures of the CNC operators governed by the characteristics of given workstation. It is well documented that the constrained posture is always associated with static muscular efforts that might lead subsequently to muscular fatigue in humans. If such a postural stress is allowed to persist on a prolonged basis it may adversely affect not only the muscles, but also the joint systems, tendons and other tissues.

Several factors which are considered to influence the static activity of the shoulder muscles are horizontal distance between the worker and the working place, position of the task, height of the working platform, shoulder joint flexion, abduction/adduction and the posture etc. (Westgaard et al., 1988). Disorder and visual discomfort have been related to the visual display unit (VDU) position and awkward posture. Present work is taken to develop a better understanding of the effect of CNC machine panel, *'height'* and *'angle'* and *'working distance'* in a HCMI environment. The parameters considered for evaluating human performance are *'search time'*, *'motor action time'* and *'force applied'* on the keys of a CNC machine panel.

Review of literature suggests that the original sources of postural stresses may be traced in terms of poor CNC workstation design. In recent years, the major emphasis is on preventing musculoskeletal injuries in the workplace. These injuries create a significant cost for industry.

II. Related Works

The rapid growth of automation has led to the development of research on human–machine interaction environment. The research aims at the design of human–machine interfaces presenting ergonomic properties such as friendliness, usability, transparency and so on. Recently, public and private organizations have engaged themselves in the enterprise of managing more and more complex and coupled systems by means of the automation. Modern machines not only process information but also act on the dynamic situations as humans have done in the past like managing manufacturing processes, industrial plants, aircrafts etc. These dynamic situations are affected by uncertain human factors. Due to the growth in use of CNC machines, resulting in an extensive human-CNC machine interaction (HCMI), complaints by the end-users about their health impairment have also been pouring in at alarming rate. All over the world concern has been voiced about the possible adverse effects of CNC machines on workers' performance, health and well being. The purpose of the present review is to put forth some major features of the previously conducted researches in the area of Ergonomics/ Human Factors Engineering pertaining to interface design with particular reference to machine's panel operation.

Further, relatively less amount of literature is available concerning human-CNC machine interface design. Hence it is important to develop Ergonomic database that can quantify effects of CNC machines panel height, angle and operators working distance on human performance.

2.1 Working Postures

Workstation's ergonomic design is dependent on considering the nature of tasks to be completed, the preferred posture of the operator and the dynamics of the surrounding environment (King and Fries, 2009). The design of the workstation needs to take into account the adjustability of the working platform, clearances under work surface, CNC machine panel and display support surfaces. 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 machining operation. Discomfort might be used as a measure for quantifying postural stresses (Kee and Lee, 2012). *Working posture* has been considered by many researchers as a focus on human performance (Choi et al., 2010; Dartt et al., 2009; Hansson et al., 2010; Lin et al., 2010 and Straker et al., 2009).

Imtiaz (2012), Imtiaz and Asghar (2011) and Imtiaz and Asghar (2010), Khan 2014a, Khan 2014b, Khan 2014c, Khan 2014d researches evaluated the effect of working postures on human performance in a computer numerically controlled (CNC) machine environment. Assessments of the performance indicated a significant effect of levels of angle of abduction and viewing angle. To eliminate discomfort and reduce injuries as far as musculoskeletal and other related problems are concerned, findings of these researches suggested that CNC machine system should be re-designed so as to achieve, a 45 degree angle of abduction and a 21 degree viewing angle. Dartt et al. (2009) assessed upper limb postures of manufacturing workers using multimedia video task analysis (MVTA). The study demonstrated fair and good results in terms of postures reliability. Estimation of muscle activation based on electromyography (EMG) is believed to be the major source of uncertainty within the EMG driven model (Koo and Mak, 2005). It is noticed that brain-machine interfaces (BMI) have become a promising technology that can aid paralyzed individuals (Kim et al., 2009). It is observed that for computer numeric control (CNC) workers, repetitions and duration contributed more to the total effort than the postures, movements and forces (Vieira and Kumar, 2007). The study assessed perceived workload using discomfort ratings and visual analogue scale (VAS). *Through present study, a more realistic approach has been proposed for measuring human performance.* Serna et al. (2007) suggested that an executive mechanism should be introduced in the modelling of behaviors associated to people with cognitive deficits.

With the accelerated pace of installation of computerized machine tools and use of human machine interaction systems, the role of ergonomists in automated industries have become crucial. The ergonomists possesses not only behavioral but also technological skills and knowledge, which is a requirement for better design of human machine interaction environment. In future industries, ergonomists will be involved for the development of effective research methodologies which could enhance significantly the productivity, product quality, quality of working life and standard of living (Imtiaz and Saraswat, 2009).

However, further research is needed in manufacturing environment, to draw guidelines for the HCMI designers as to what level of anthropometric parameters will be really required to enhance the human performance. It is noticed that almost all researchers have strongly stressed on musculoskeletal disorders as the major source for human performance decrement. Keeping this in view, the thoughts of researchers on discomfort and musculoskeletal disorders are reviewed in the following section.

2.1.1 Discomfort and Musculoskeletal Disorders

A number of previous studies suggest mainly two types of adverse health outcomes for prolonged postural activity at work, first body discomfort and the second work-related musculoskeletal disorders (WMSDs) (Boussenna et al., 1982; Kee and Karwowski, 2003; Kee and Karwowski, 2004 and Reid et al., 2010). Postural discomfort can also arise from past injury, current health, psychosocial variables and present diagnosis of WMSDs (Messing et al., 2006). Understanding of the cause-and-effect relationships with respect to perceived and reported body discomfort levels and occupational activities can contribute to the prevention and management of work-related musculoskeletal disorders (WMSDs). Work-related musculoskeletal disorders (WMSDs) are an important health concern for the industry. WMSDs are an aggregation of disorders of the muscles, tendons and nerves that are caused by the work. The WMSDs include the specific disorders such as tendonitis as well as the syndromes that are more general or the disorders characterized by the pain in the upper extremities. Many other researchers have addressed the problems associated with musculoskeletal disorders (Aaras et al., 2002; Amell and Kumar, 2000; Cook et al., 2000; Genaidy et al., 2005; Helland et al., 2008 and Village and Trask, 2007). Yun et al. (2001) investigated the relationship between the self-reported musculoskeletal symptoms and the related factors among visual display terminals (VDT) operators working in the banks. The subjects of the study were 950 female bank tellers. The study was carried out to specify the prevalence of the WMSDs and to identify the demographic and task-related factors associated with the WMSD symptoms. The study indicated the percentages of the subjects reported the disorders of the shoulder, lower back, neck, upper back, wrist and the fingers as 51.4, 38.3, 38.0, 31.2, 21.7 and 13.6 respectively.

Discomfort as a result of joint positions and postural activities are immediately noticed. Also, it is much easier and faster to quantify discomfort noted from occupational postural activity and develop guidelines. Work procedure guidelines added to physiology, observation and direct measure results will aid in forming risk models of possible occupational task hazards and their associated cumulative trauma disorders (CTDs). Derivations of these methodologies have been demonstrated in validated ergonomic risk assessment tools for the lower back (Waters et al., 1993) and upper extremities (McAtamney and Corlett, 1993). Before any conclusion is drawn, the body discomfort must be understood and defined. *Body discomfort in terms of postures and activities, can be defined as having sensations of pain, soreness, stiffness, numbness or tingling* (Helander and Zhang, 1997; Meyer and Radwin, 2007 and Reid et al., 2010). These studies reveal that many effects of discomfort are due to physiological reasons related to the body's internal biomechanics and muscle fatigue capacities. These factors actively change as joints articulate, muscle contract and internal body pressure regulate. Tasks involving prolonged exposure to working postures and or repeated activities are associated to body discomfort (Corlett and Bishop, 1976). Non-neutral joint angles (Van Wely, 1970) and extrinsic contact stress on lower extremities body tissue from work environments (Chung et al., 2005) are also known to be uncomfortable for people if sustained. Furthermore, holding time of these postures is directly dependent on the perceived levels of discomfort, therefore the torques and fatigues induce through postures indirectly affects the time people can maintain postural loading (Corlett and Bishop, 1976).

The job/task related variables can be divided into *three* general categories (Reid et al., 2010). First the joint positions, second the body postures and third the task performance requirements (occupational activities). Joint position shows how body discomfort can relate to joint deviation. Body postures commonly studied are standing and chair sitting whereas awkward postures such as tiptoeing while standing, stooping, floor sitting, squatting, kneeling, imbalances and lying down are less studied. The category of task performance comprises dynamic movement. Common movements of this category include walking, pushing, pulling, lifting, lowering, stacking and stair/ramp climbing. Prolonged kneeling, squatting and knee flexion in general have been correlated to lower extremities discomfort for occupations involving manufacturing tasks, assembly of automobiles, ships and aircraft and farming tasks (Bruchal, 1995).

Studies have also been conducted between genders. These studies assess joint body discomfort during standing postures for men (Kee and Karwowski, 2001) and women (Kee and Karwowski, 2004). Of the body's major joints, the hip is the most likely to exhibit discomfort in a sustained position. This is applicable to both *standing* and chair sitting postures. Results of the *female* study show that hip joint deviations are the most uncomfortable joint motions to sustain statically. Evidence shows that regardless of gender, the hip seems to be more prone to postural discomfort for each of its degree of freedom when static position duration is a minimum of 60 seconds (at least for standing postures). Additionally, *females* were found to be more resilient to discomfort compared to males, but only for joint rotational motions. Kee and Karwowski (2004) found that female joint discomfort levels were verified to be higher than their male counterpart by 13% ($p < 0.01$). This infers that task requiring joints to maintain high angles of deviation are likely to be more uncomfortable for women than for men. Another study (Messing et al., 2008) noticed that female population had a higher prevalence of lower extremity discomfort than their male counterparts. Even though female discomfort may be high for the lower extremity, evidence shows that women still have a greater lower extremity joint range of motion than do men (Chung and Wang, 2009 and James and Parker, 1989).

As mentioned earlier, a body *posture* is simply a collection of joint positions for each major joint of the body. As a result, the same variables of static hold time, body endurance, strength requirements and task exposure time will still apply towards the development of body discomfort. Various researches have been carried out to investigate the effects of work place layout and working postures (Cook et al., 2004; Gustafsson and Hagberg, 2003; Lindegard et al., 2005; Mital and Pennathur, 2004; Nevala-Puranen et al., 2003 and You et al., 2005). When categorizing *work postures*, there are *three* that are mentioned in the literature: standing, sitting (assumed to be in a chair) and awkward postures (Gallagher, 2005). A multitude of investigations have examined associations between the *posture of standing* and discomfort (Balasubramanian et al., 2009; Cham and Redfern, 2001; Chung et al., 2003; Ngomo et al., 2008; Redfern and Cham, 2000 and Ryan, 1989). Standing differs from other postures in that total body weight is supported and distributed bilaterally along each leg and then into each foot. Chung et al. (2003) notices that the standing posture requires knee flexion angles to be less than 30 degrees (along the vertical axis) and distance between the feet of approximately 40 centimeters. *Research* to be carried out on standing discomfort can also be dispersed between types of foot instances, prolonged standing durations and impact of floor surface material for the foot.

Balasubramanian et al. (2009) noticed a significant difference existed between the fatigue rates of prolonged static standing and dynamic standing (consistent movement within a standing area). Messing et al. (2006) too observed that periods of prolonged standing with little to no movement can cause low levels of comfort. Ngomo et al. (2008) suggests that the significant association that resulted between the static standing and lower leg/foot discomfort ($p=0.046$) of their research may be caused by the combination of lowered blood pressure in the legs, mechanical compression on internal tissue and possibly muscle tissue damage. Pope et al. (2003) found that over time, people who stand for more than 2 hours without a change of posture for occupations where they have been working for more than one year, showed an association to hip discomfort. Prolonged standing itself is not the only contributor of the lower extremity pain. Floor surface conditions can also influence the result of perceived discomfort for the lower extremity (Cham and Redfern, 2001). Softer floor surfaces or floor mats as compared to hard are perceived as more comfortable (Redfern and Chaffin, 1995 and Redfern and Cham, 2000). However, the results of their study showed extremely soft floor surfaces can be just as uncomfortable as hard surfaces.

Discomfort is not limited to limb segment positions and body posture alone. Discomfort also may arise due to activities that are performed for the sake of finishing a task (Au and Keir, 2007; Fostervold et al., 2006; Klopcar et al., 2007; Lee and Su, 2008 and Straker et al., 2008). McGlothlin (1996) reviewed several postures and activities that were utilized by the beverage delivery employees which included sitting, kneeling, squatting, pushing, pulling, lifting, lowering, stacking or unstacking items, walking and stair or ramp climbing. The investigation showed that knee discomfort symptoms were the most reported by employees for the lower extremity.

The aforementioned literature highlight that the human performance is highly affected in the presence of discomfort and musculoskeletal disorders. The following section reviews the effects of anthropometric factors on human performance.

2.1.2 Effects of Anthropometric Factors

The *anthropometric factors* such as abduction, adduction, flexion, extension, rotation hence forth are considered frequently in the design of the systems like human-computer interaction, human-CNC machine interaction and so on. A review of the literature finds a relatively large number of studies on these factors (Bergmann et al., 2011; Cadogan et al., 2011; Khan et al., 2010; Lau and Armstrong, 2011; MacWilliams et al., 2010; Nikooyan et al., 2010; Peterson and Rayan, 2011 and Suprak, 2011). The influence of external factors such as arm posture, hand loading and dynamic exertion on shoulder muscle activity is needed to provide insight into the relationship between internal and external loading of the shoulder joint as explored by Antony and Keir (2010). The study collected surface electromyography from 8 upper extremity muscles on 16 participants who performed isometric and dynamic shoulder exertions in three shoulder planes (flexion, mid-abduction and abduction) covering four shoulder elevation angles (30^0, 60^0, 90^0 and 120^0). Shoulder exertions were performed under three hand load conditions: no load, holding a 0.5 kg load and 30% grip. It was found that adding a 0.5 kg load to the hand increased shoulder muscle activity by 4% maximum voluntary excitation (MVE), across all postures and velocities. Also the study concluded that performing a simultaneous shoulder exertion and hand grip led to posture specific redistribution of shoulder muscle activity that was consistent for both isometric and dynamic exertions.

Kuppuswamy et al. (2008) determined that the abduction of one arm preferentially activates erector spinae muscles on the other side to stabilize the body. The study hypothesizes that the corti cospinal drive to the arm abductors and the erector spinae may originate from the same hemisphere. The study also has implications for the design of measures to promote recovery and rehabilitation of motor function in disorders such as stroke and spinal cord injury. Terrier et al. (2008) explored that the shoulder is one of the most complex joints of the human body, mainly because of its large range of motion but also because of its active muscular stabilization. The study presented an algorithm to solve the indeterminate problem by a feedback control of muscle activation, allowing the natural humerus translation. In this study the abduction was considered in the scapular plane, accounting for the three deltoid parts and the rotator cuff muscles. Gutierrez et al. (2008) determined the effects of prosthetic design and surgical technique of reverse shoulder implants on total abduction range of motion and impingement on the inferior scapular neck. The study concluded that the neck-shaft angle had the largest effect on inferior scapular impingement, followed by glenosphere position.

Levasseur et al. (2007) explored that a joint coordinate system allows coherence between the performed movement, its mathematical representation and the clinical interpretation of the kinematics of joint motion. The study tried to investigate if mathematical alignment of the reference and moving coordinate system axes could facilitate the kinematic interpretation of a simple abduction movement without introducing additional coupled motion. The results obtained revealed a difference in the interpretation of the starting angles between the International Society Biomechanics (ISB) joint coordinate system and the aligned coordinate system. No difference was found in the interpretation of the angular range of motion. Wickham et al. (2010) performed an experiment to obtain electromyographic (EMG) activity from a sample of healthy shoulders to allow a reference database to be developed and used for comparison with pathological shoulders. In this study temporal and intensity shoulder muscle activation characteristics during a coral plane abduction/ adduction movement were evaluated in the dominant healthy shoulder of 24 subjects. The study concluded that the most reproducible patterns of activation arose from the more prime movers muscle sites in all EMG variables analyzed and although variability was present, there emerged invariant characteristics that were considered normal for this group of non pathological shoulders. Gielo-Perczak et al. (2006) conducted a study to test whether glenohumeral geometry is co-related with upper arm strength. The isometric shoulder strength of 12 subjects during one-handed arm abduction in the coronal plane in a range from 5^0 to 30^0, was correlated with the geometries of their glenoid fossas. The study concluded that the new geometric parameter named as the area of glenoid asymmetry (AGA) is a distinguished factor which influence shoulder strength when an arm is abducted in a range from 5^0 to 30^0.

Many researchers have suggested a compensatory strategy to decrease the load on the fatigued shoulder musculature (Fujiwara et al., 2009; Fuller et al., 2009; Nabhani et al., 2009 and Yoshizaki et al., 2009). Mukhopadhyay et al. (2007) explored that industrial jobs involving upper arm abduction have a strong association with musculoskeletal disorders and injury. The study pointed out that there is still paucity of data on the different risk factors that are responsible for the genesis of such disorders or injuries. In this study 36 right handed male university students participated in a full factorial model of three forearm rotation angles (60^0 prone and supine and neutral range of motion), three elbow angles (45^0 , 90^0 and 135^0), two exertion frequencies (10 and 20/min) and two levels of pronation torque (10% and 20% MVC). The discomfort rating after each five-minute treatment was recorded on a visual analogue scale. The findings of the study indicated that with the upper arm in abduction, an elbow angle of 45^0 and forearm prone, are a posture vulnerable to injury and should be avoided. Biomechanical risk factors across different mouse positions within a computer controlled workstation were explored by Dennerlein and Johnson (2006). One of the two studies with 30 subjects (15 females and 15 males) examined the three mouse positions: a standard mouse (SM) position with the mouse placed to the right of the keyboard, a central mouse (CM) position with the mouse between the key board and the human body and a high mouse (HM) position using a keyboard drawer with the mouse on the primary work surface. The second study examined two mouse positions: the SM position and a more central position using a different keyboard named normal mouse (NM) position. In this work the muscle activity of the wrist and upper arm postures were recorded through the electromyography (EMG) technique. The CM position was found to produce the most neutral upper extremity posture across all measures. The HM position has resulted the least neutral posture and highest level of muscle activity. The study also indicated that the NM position reduces wrist extension slightly and promote a more neutral shoulder posture as compared to the SM position. The study concluded that the HM position was least desirable whereas the CM position result the minimum awkward postures.

Peter and Jack (2006) determined the differences in biomechanical risk factors during the computer tasks. The study was conducted with the 30 touch-typing adults (15 females and 15 males). The subjects were asked to complete five different tasks: typing text, filling of a html form with text fields, text editing within a document, sorting and resizing objects in a graphics task and browsing and navigating a series of internet web pages. The study reported that the task completion with the help of both the mouse and the keyboard result the higher shoulder muscle activity, larger range of the motion and the larger velocities and acceleration of the upper arm. Also the findings indicated that on comparing different types of the computer tasks the use of the mouse as compared to the keyboarding is prevalent and is associated with the more constrained postures of the wrist and shoulder. Many studies focused on the measurements of scapular motions (Andel et al., 2009; Baker et al., 2007; Kraker et al., 2009 and Salvia et al., 2009). Susan and Andy (2006) reported large and statistically significant reductions in muscle activity by modifying a workstation arrangement of an ultrasound system's control panel. In this study, the right suprascapular fossa activity indicated a reduction of muscle activity by 46%, between a postural stance of 75 and 30 degrees abduction. Choudhry et al. (2005) in their study compared the anthropometric dimensions of the farm youths of the north-eastern region of the India with those of China, Japan, Taiwan, Korea, Germany, Britain and USA. The study concluded that all the anthropometric dimensions of the Indian subjects were lower than those from the other parts of the world. Human laterality is considered to be one of the most important issues in human factors engineering. Hand anthropometric data have indicated differences between right and left-handed individuals and between females and males. A study was carried out by Yunis (2005) on the hand dimensions of the right and left-handed Jordanian subjects. The results indicated that there were significant differences in the hand anthropometric data between right and left-handed subjects as well as between the females and males subjects. Shoulder function involves the complex interaction among several muscles even in the standardized arm positions and simple movements. EMG patterns provide the useful information on the shoulder function in the non-fatigued muscles during the static contractions.

Prolonged static posture has been identified as a major risk factor for work-related neck and upper limb disorders. Researchers have proposed various methods based upon anthropometric factors for the evaluation of human fatigue (Karwowski et al., 2006; Kedgley et al., 2007; Liu et al., 2003; Lowe, 2004; Rozmaryn et al., 2007 and Veeger and Helm, 2007). Alan et al. (2003) explored in their study that the constant intramuscular (IMP) / EMG relationship with increased force may be extended to the dynamic contractions and to the fatigued muscles. In this study IMP and EMG patterns were recorded through shoulder muscles in the three sessions: (i) brief static arm abductions at the angles from 0-90 degrees with and without one kg load in the hands, (ii) dynamic arm abductions at velocities from 9-90 degrees per second with and without one kg load in the hands and

(iii) prolonged static arm abduction at 30 degrees for 30 minutes followed by the recovery. It was found in the study that during the brief static tasks the IMP and EMG patterns increased with the shoulder torque. Also the increase was more during the dynamic contractions and particularly the EMG patterns increased significantly with the speed of abduction. Jung-Yong et al. (2003) determined the upward lifting motion involved at the scapula at various shoulder angles. In particular, 90 and 120 degrees of flexion, 30 degrees of adduction, and 90 degrees of abduction were found to be the most vulnerable angles based on the measured maximum voluntary contractions (MVCs). The average root mean square value of the EMG increased most significantly at 90 to 150 degrees of flexion and at 30 and 60 degrees of abduction. The increasing demand of the anthropometric data for the design of the machines and personal protective equipments to prevent the occupational injuries has necessitated an understanding of the anthropometric differences among occupations.

Hongwei et al. (2002) identified the differences in various body measurements between various occupational groups in the USA. The analysis of the data indicated that the body size or the body segment measurements of some occupational groups differ significantly. The optimum height of the table of the operating room for the laparoscopic surgery was investigated by Smith et al. (2002). The study concluded that the optimum table height should position the handles of the laparoscopic instrument close to the surgeon's elbow level to minimize discomfort. The study determined the optimum table height as 64 to 77 cms above the floor level. In the retail supermarket industry where the cashiers perform repetitive light manual material-handling tasks during scanning and handling products, the cases of the musculoskeletal disorders and the discomfort are high. Lehman et al. (2001) conducted a research to determine the effect of working position (sitting versus standing) and scanner type (bi-optic versus single window) on the muscle activity. Ten cashiers from a Dutch retailer environment participated in the study. Cashiers exhibited the lower muscle activity in the neck and shoulders when standing and using a bi-optic scanner. The shoulder abduction was also less for the standing conditions.

Fine et al. (2000) conducted a case study in an automobile assembly plant. There were 79 subjects who reported shoulder pain. More than one-half also had positive findings in a physical examination. Subjects who were free of shoulder pain were randomly selected. Forty-one percent of the subjects flexed or abducted the right arm "severely" (above 90 degrees) during the job cycle, and 35% did so with the left arm. Disorders were associated with severe flexion or abduction of the left (odds ratio (OR) 3.2) and the right (OR 2.3) shoulder. The risk increased as the proportion of the work cycle exposure increased. The findings concluded that, the shoulder flexion or abduction, especially for 10% or more of the work cycle, is predictive of chronic or recurrent shoulder disorders. David et al. (1988) investigated the effect of the anthropometric dimensions of the three major ethnic groups in the Singapore. The study was carried out with the help of the 94 female visual display units (VDU) operators. Few anthropometric differences were recorded among the Chinese, Malays and Indians. On comparing the data with the Americans and Germans, the three Asian cohorts were found smaller in the body size. Because of the smaller body build the Asian VDU operators preferred a sitting height of about 46 cms and a working height of about 74 cms while as the European operators preferred the sitting and working heights as 47 cms and 77 cms respectively. Also the Asian as well as the European VDU operators are comfortable in a posture with slightly open elbow angle. The position of the upper arm and head, as an indicator of load on the shoulder and risk of shoulder injury for workers performing electromechanical assembly work, was explored by Westgaard et al. (1988). In this study postural angles, in terms of flexion/extension and abduction/adduction of the right upper arm and the shoulder joint, as well as flexion/extension of head and back were measured for a group of female workers. Adopting a posture with an arm flexion of less than 15 degrees, an arm abduction of less than 10 degree and using a light (0.35 kg) hand tool, resulted in a 20% incidence of sick leaves due to shoulder injuries of workers employed between 2-5 years, and 30% incidence for those employed more than 5 years. This was significantly lower for other groups working with higher arm flexion. The study concluded that the magnitude of the postural angles of the shoulder joint influenced the shoulder load. Another study for standing, supported-standing, and sitting postures was carried out with subjects simulating assembly work in places with poor leg space by Bendix et al. (1985). The postures and the upper trapezius muscle load were examined using statometric and electromyographic (EMG) methods, respectively. While supported-standing or sitting, the lumbar spine moved toward kyphosis, even with no backward rotation of the pelvis. In adopting the position for anteriorly placed work, the arms were raised 30 degrees forward or more, the trunk was flexed as well. It was concluded in the study that, if leg space is poor, variation between supported-standing and standing should be encouraged, and an ordinary office chair should be avoided. Also, the working level should be arranged so that it is lower than 5 cm above the elbow level if no arm/wrist support is possible.

Viewing angle is one of the important considered factors in the design of the systems like human-computer interaction, human-CNC machine interaction and so on. A review of the literature finds a relatively large number of studies on the viewing angle. Smith et al. (2010) explored that the attention mediates access of sensory events to higher cognitive systems and can be driven by either top-down voluntary mechanisms or in a bottom-up, reflexive fashion by the sensory properties of a stimulus. The study investigated the effect of an experimentally induced opthalmoplegia on voluntary and reflexive attentional orienting during visual search. The study observed that abducting the eye into the temporal hemifield elicited deficits of both voluntary and reflexive attention for targets that appeared beyond the oculomotor range. Kong-King and Der-Song (2007) determined the viewing distance and screen angle for electronic paper (E-Paper) displays under various light sources, ambient illuminations and character sizes. Findings of this study indicate that mean viewing distance and screen angle should be 495 mm and 123.7 degrees (in terms of viewing angle, 29.5 degrees below the horizontal eye level), respectively. Proper visualization of the background of surgical field is essential in the laparoscopic surgery and it reduces the risk of iatrogenic injuries. One of the important factors influencing visualization is the viewing distance between surgeon and the monitor.

Shallaly and Cuschieri (2006) explored that the maximal viewing distance increases with increasing VDU monitor size. Another study for visual display unit (VDU) work environment was carried out by Svensson and Svensson (2001). In this study two viewing angles, namely 3 degrees above the horizontal and 20 degrees below the horizontal, were considered. The findings concluded that the load on the neck and shoulders was significantly lower at 3 degrees as compared to 20 degrees. Jan et al., (2003) explored that low VDU screen height increases the viewing angle and also affects the activity of the neck extensor muscles. Ayako et al., (2002) determined the effects of the tilt angle of a notebook computer on posture and muscle activities. It was concluded in the study that at 100 degree tilt angle, the subjects had relatively less neck flexion. Visual display units are widely used in the industries. The optimization of their orientation is a critical aspect of the human-machine interaction and impacts on the worker health, satisfaction and performance. Due to increase in the visual and musculoskeletal disorders related to VDU use, a number of ergonomic recommendations have been proposed in order to combat this problem. Fraser et al., (1999) observed that, the monitor position, 18 degree below eye level had no significant effect on the position of the neck relative to the trunk while, the mean flexion of the head, relative to the neck increased 5 degrees. Burgess-Limerick et al., (2000) determined optimal location of the visual targets as 15 degrees below horizontal eye level. Nowadays, computer-based consumer interactions are becoming common. Effective interactions are crucial for commercial success and aspects such as vision and control are important determinants. Adjustability effect of the touch screen displays in a food service industry was investigated by Batten et al., (1998). To determine the optimal viewing angle or range of a given touch-screen display, an anthropometric analysis was carried out. The results recommended the adjustable range of the touch-screen display as 30 to 55 degrees to the horizontal. Furthermore, the results of the study indicated that the subjects adjusted the touch-screen between the angles of 19 and 54.5 degrees to the horizontal. The study concluded that there is no optimal viewing angle of the touch-screen displays with a dynamic set of the user heights and a static workstation height. The displays should be adjustable through a range that accommodates multiple users and workstations and provides adjustment to compensate for other miscellaneous variables such as glare etc. Chen and Chiang (2011) investigated the effects of panel arrangement on search performance. The three variables of this study were panel arrangement, movement distance and icon size. Participants were asked to search for target items with in a four stimulus array. Exposure duration was adopted as the dependent factor. The study was concerned with the user's icon- clicking distance focusing on two distances, namely, the distance between the start position and the first icon on the panel and the distance between two icons. Results showed that the panel arrangement, movement distance and icon size have caused significant effects on the user's search performance. The study explored that the results obtained can form design guidelines which are applicable for future human-computer interface design.

Path planning is a problem encountered in multiple domains. Due to the voluminous and complex nature of the data, working distance planning in demanding environments requires the use of automated planners. In order to understand how to support human operators in the task of working distance planning with computer aids, Cummings et al. (2012) conducted an experiment with a prototype path planner under various conditions to assess the effect on operator performance. The result indicated that the type of optimizing cost function affected performance, as measured by metabolic costs, sun position, path distance and task time. Stoffregen et al. (2000) explored relations between visual performance and postural control. Variability in postural sway was analyzed in the context of variations in supra-postural visual tasks. Stoffregen et al. (2000) varied target distance (near vs. far) and visual task (inspecting a blank target vs. counting the frequency of letters in a block of text). The findings noticed that variability in postural sway was reduced when participant fixated near targets as opposed to far targets. Also, postural sway during the visual search task was reduced relative to sway during the inspection of blank targets. It was observed that the search task placed more restrictive constraints on the visual system, and that postural sway was reduced to facilitate visual search. The results of the study support the hypothesis that postural control is not an autonomous system, but is organized as part of an integrated perception-action system. *The study concluded that the postural control can be used to improve visual performance.*

The researchers have suggested that objects appear farther away if more effort is required to act upon them. Woods et al. (2009) attempted to replicate several findings supporting this view but found no effort-related effects in a variety of conditions differing in environment, type of effort and intention to act. Woods et al. (2009) did find an effect of effort on verbal reports when participants were instructed to take into account nonvisual (cognitive) factors, no effort-related effect was found under apparent and objective distance instruction types. The study concluded that in the paradigms tested, effort manipulations are prone to influencing response calibration because they encourage participants to take nonperceptual connotations of distance into account while leaving perceived distance itself unaffected. If distance, shape and size are judged independently from the retinal and extra-retinal information at hand, different kind of information can be expected to dominate each judgment, so that errors in one judgment need not be consistent with errors in other judgments. Brenner and Damme (1999) examined how adding information that improves one judgment influences the others. The study conclude that the judgments are quite independent in the sense that no attempt is made to attain consistency but that they do rely on some common measures such as that of distance. Tasks that require people to make estimates of the length of the line segments, such as the line bisection task are commonly used to investigate attentional asymmetries. Foster et al. (2007) noticed that people often attend more to novel than routine conditions and therefore participants might have overestimated the distance associated with leftward versus rightward movement because right-handed people more frequently move their right hand in a rightward direction and learn to read and write using rightward movements. Thus, leftward movements might be more novel and more attended than rightward movements and this enhanced directional attention might have influenced estimates of distance.

Retrieving when an event occurred may depend on an estimation of the age of the event (distance-based processes) or on strategic reconstruction processes based on contextual information associated with the event (location-based processes). Bastin et al. (2004) evaluated the processes used by the participants to recognize the stimuli and retrieve their list of occurrence. The results showed that aging disrupts location-based processes more than distance-based processes. In addition, a limitation of speed of processing and working-memory capacities was the main predictor of age-related differences on location-based processes, whereas working-memory capacities mediated partly age differences on distance-based processes. Hinton et al. (2010) employed a novel five-term relational reasoning paradigm during functional magnetic resonance imaging to investigate neural correlates of the symbolic distance effect. Overall, the findings demonstrate a crucial role for parietal cortex during relational reasoning with a spatially ordered array. Phillips et al. (2007) developed a human-machine interaction (HMI) model for the human operator (HO) performing five simultaneous tasks and characterized by a strategy function. Five levels of total machine-initiated baud rate (BIN) were generated by the multi-attribute task battery (MATB) and five HO baud rates (BO) were than recorded. Result indicated that with increasing BIN levels: there was an overall increase in BO and overall decrease in baud ratio. It was noticed that these results are due to a decreasing HMI performance and divergence of the strategy function from a unity model paradigm.

The above researchers have been concerned mainly with the effect of antropometric factors on human performance. The present study considers the impact on performance in a human-CNC machine interface (HCMI) environment. Anthropometric factors in the present study are incorporated in terms of variability considered in CNC machine working environment. Keeping in view the above research works with respect to musculoskeletal disorders and anthropometric factors, three factors are selected for this work. First the CNC machine panel height, second the panel angle and third the working distance. The domain needs to enrich more for the benefit of the researchers and practitioners.

2.2 Cognitive Performance

Designing human-machine interfaces that respect the ergonomic norms and following rigorous approaches constitute a major concern for automated systems designers. The increased need on easily accessible and usable interfaces leads researchers in this domain to create methods and models that make it possible to evaluate these interfaces in terms of utility and usability. Two different approaches are currently used to evaluate human-machine interfaces

(Chikhaoui and Pigot, 2010), empirical approaches that require user involvement in the interface development process and analytical approaches that do not associate the user during the interface development process. This work presents studies of user performance on three principal tasks (cognitive, motor action and applied force) of the machine panel interface, developed in the context of CNC machine system. Chikhaoui and Pigot (2010) investigated that cognitive models show better accuracy of the user performance. In order to provide a comfortable environment, attention should be brought to ensure that people should easily access and manage the information in the environment. This can be reached by providing the user an interface that is accessible, usable and efficient (Joon et al., 2007). Each human-machine interface must be clear enough, to reduce the cognitive effort and allowing a good interaction with the environment. Therefore, the evaluation of human-machine interfaces appears a significant contribution in the design of applications and systems dedicated for automated machines.

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 (Imtiaz and Asghar, 2007). The concerned areas of cognitive ergonomics include co-operative work, user interface design, modelling of users and systems, problem solving, learning and system design- especially the design of automation. The world of competitive manufacturing demands that production system must become more flexible, more adaptable, more productive, more cost efficient, more schedule efficient and more quality driven (Layer et al., 2009; Lewis and Boyer, 2002 and Maturana et al., 1999). Improving adaptability necessarily implies a focus on the human operator, the center of manufacturing processes. Human cognitive demand considerations, as well as the human quality of work intersection with production system performance parameters, should be evaluated and optimized (Genaidy et al., 2007a and Genaidy et al., 2007b). 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. Rasmussen (2000) has noted that individuals work routines have been enlarged by automation and widening individuals work domain, which in effect moves tasks to a higher cognitive level where flexibility and adaptation to task demands are essential. This higher cognitive level of involvement has been discussed by Mikkelsen et al. (2002) within the contexts of the job strain model and the corresponding psychological effects associated with high work load, increased work pressure, diminished job control, training and use of new technologies. An integrated approach based on the unity of cognition and behavior within activity theory (Bedny and Karwowski, 2006) indicated that activity is a complex system of intimately related cognitive and motor components (actions) specific to humans and is contained in a coherent system of internal mental and motivational processes and external behavior that are systemically combined and directed to achieve the current conscious goal (Bedny et al., 2001). Although the advent of adaptable production systems has produced positive economic benefits over the last several years at a corporate level, the sustainable effects of this process change on individuals have not been adequately quantified. Numerous researchers (Genaidy and Karwowski, 2003; Genaidy et al., 2005; Schultz et al., 2003; Carayon and Smith, 2000; Eklund, 2000 and Lee and Lee, 2001) have documented the fact that little research has been conducted to evaluate the individual's situation particularly as it relates to information processing and human cognition (Richardson et al., 2006). Layer et al. (2009) noticed that the human performance in manufacturing environments depends on the cognitive demands of the operator. The process of conducting a cognitive task analysis is discussed by Klein et al. (1997) as *"a method for getting inside the heads of people, to understand the cues and patterns and relationships they perceive, the knowledge they are using and the strategies they are applying". Cognitive task analysis not only evaluates what the human subject is doing, but also what cognitive processes are involved to determine how and why operators make decisions.* Many researchers have addressed the problems associated with cognitive environments (Bula and Wietlisbach, 2009; Feigh, 2011; Ferris et al., 2008; Latham et al., 2008; Phillips and Madhavan, 2011 and Ross, 2009). With the continued advancement of technology, operators are often responsible for performing several tasks simultaneously, which increases the relative load associated with task performance (Phillips and Madhavan, 2011).

Among the properties that account for the effectiveness of images in human cognition, their analog character is the property that has received the most consideration (Denis, 2008; Denis and Kosslyn, 1999 and Richardson, 1999). Mental images are depictive representations of which internal structure is based on semantics of resemblance. Not only do mental images contain information, but also this information is organized in meaningful patterns, and this organization is mapped onto the organization of information in the physical entities represented by the images. The structural isomorphism between images and objects or scenes is attested by the fact that they preserve topological relationships between parts of objects, and even detailed metric information, such as the relative distances between these parts (Denis, 2008). The theory of imagery most often adopted is based on the concept that images can preserve the Euclidean metrics of the objects perceived. This concept lies at the core of most theoretical hypotheses regarding the architecture and function of the human cognitive system. A further step in generalizing the symbolic distance effect consisted of searching for evidence collected when people mentally process novel objects. Predicting human performance and mental workload in multiple task situations at an early stage of system design can save a significant amount of time and cost (Wu and Liu, 2009). Performing two tasks concurrently is one of the common activities in human-machine interaction. Operators in control rooms in manufacturing industry may operate a device and monitor several displays at the same time. Predicting human performance and mental workload in dual task conditions at an early stage of system design can save a significant amount of time and cost in comparison to revising the systems at a later stage of system development.

Cognitive architecture the adaptive control of thought-rational (ACT-R) is developed to simulate and understand human cognition (Anderson et al., 2005 and Chikhaoui and Pigot, 2010). It consists of multiple modules such as declarative, goal and perceptual-motor, integrated through a central production system in order to produce coherent cognition. ACT-R is a hybrid architecture that combines two subsystems: symbolic system containing knowledge and subsymbolic system evaluating knowledge activations. The symbolic system includes the declarative memory, which contains the semantic unities of information called *'chunks'* and the procedural memory contain the production rules (Newell, 1990). The subsymbolic system assigns activations to chunk (semantic knowledge) and rules (procedural knowledge), which helps to choose the more predominant knowledge available at a specific time. Each module is associated with one or more buffers. The different modules are responsible to place chunks in buffers in order to be detected by the production system that responds to the information contained in buffers (Anderson et al., 2004). In ACT-R, the perceptual and motor modules are used to simulate interfaces between the cognitive modules and the external world. The perceptual modules allow the model to attend to *visual* and aural stimuli, while the motor modules are responsible for preparing and executing basic motor actions such as *key presses* and mouse movements (Bothell, 2004 and Byrne, 2001). The visual module that is part of the perceptual modules, is decomposed on two subsystems, the position system (where) and the identification system (what). These two subsystems work together in order to send the specified chunk to the visual buffer that the cognitive modules use. The positional system is used to find objects. When a new object is detected, the chunk representing the location of that object is placed in the visual-location buffer according to some constraints provided by the production rule. The identification system is then used to attend to locations which have been found by the positional system. The chunk representing a visual location, will request the identification system to shift visual attention to that location. The result of an attention operation is a chunk, which will be placed in the visual buffer and should be placed then in the declarative memory (Bothell, 2004 and Byrne, 2001). The motor module contains only one buffer through which it accepts requests. Two actions are available in ACT-R, to click with the mouse or press a key on a virtual keyboard. The ACT-R model is constructed mainly upon three phases. First, the visual phase which consists of two steps, localizing the object to perceive and then identifying it. The location and identification phases lasts 185 milliseconds (Bothell, 2004 and Byrne, 2001). Secondly, the recognition phase begins when the chunk of the object is placed in the visual buffer. This phase implies to recover that specific chunk from the declarative memory. The result of this phase is a chunk that represents the object with some characteristics as color, localization, name and kind of object. Third, the motor phase consists of activating the motor actions via a request to the motor buffer, in order to click on the object. The human-machine interaction involves several human capabilities. It supposes that the user determines a goal he wants to reach, perceives the interface he faces, evaluates the correspondence between his goal and the interface proposed, solves the problems and finally plans an interaction he will then execute on the interface (John and Kieras, 1996). The human machine interaction supposes four principal generic actions. First, the initialization where the user determines the goal he wants to reach. Secondly, the visual phase where the user perceives the interface he looks at mainly under visual features. Third the cognitive phase, where he evaluates the adequacy between his goal and the interface and decides how to reach his goal. Fourth the user plans the motor action and executes it on the interface (John and Kieras, 1996).

Keeping in view the above research work with respect to cognitive performance, three response variables are selected for this work. First the search time, second the motor action time and third the applied force. The domain of effect of age on human-performance is now reviewed in the following section.

2.3 Effects of Age on Human Performance

Slowing of motor performance in human aging is a well demonstrated clinical observation, both studied with simple and complex motor tasks (Jimenez-Jimenez et al., 2011; Ruff and Parker, 1993 and Shimoyama et al., 1990). Several studies showed gender-related differences in the ability to perform some fine motor tasks as well. Finger tapping (FT) frequency lowers with advancing age (Cousins et al., 1998; Elias et al., 1993 and Hermsdorfer et al., 1999), and some studies have also described men as faster than women in the FT test (Arnold et al., 2005 and Ylikoski et al., 1998). Aging seems to influence the performance of simple or complex reaction time tasks, including visual reaction time, being the response times longer in elderly people (Chen et al., 1994; Nissen and Corkin, 1985 and Pelosi and Blumhardt, 1999). Behavioral performance in older adults is often characterized by normal error rates but longer response latencies compared to younger adults. The slowing of reaction times might reflect a compensatory strategy to avoid errors and might be associated with performance monitoring alterations. Endrass et al. (2012) investigated whether the ability to compensate for potential deficits influences age-related differences in performance monitoring. The study used a modified flanker task with either accuracy or speed instruction. The finding indicated reliable differences between conditions: accuracy, reaction times and error-related negativities were reduced in the speed compared with the accuracy condition. Also, older adults showed smaller error-related negativities compared with younger adults and the reduction was more pronounced in the speed condition. Further, the study concluded that similar-sized error-related and correct-related negativities were found in older adults. The results indicate that performance monitoring deficits in older adults are related to deficits in behavioral performance, at least if they are forced to respond quickly.

Research on age-related cognitive change traditionally focuses on either development or aging, where development ends with adulthood and aging begins around 55 years (Germine et al., 2011). The said approach ignores age-related changes during the 35 years in between, implying that this period is uninformative. Germine et al. (2011) investigated face recognition as an ability that may mature late relative to other abilities. The study using data from over sixty thousand participants, traced the ability to learn new faces from pre-adolescence through middle age. In three separate experiments, the finding show that faces learning ability improves until just after age 30- even though other putatively related abilities (inverted face recognition and name recognition) stop showing age-related improvements years earlier. The study data provide the behavioral evidence for late maturation of face processing and dissociation of face recognition from other abilities over time demonstrates that studies on adult age development can provide insight into the organization and development of cognitive systems. Multiple causes contribute to the prolonged reaction-times (RT) observed in elderly persons (Bautmans et al., 2011). The involvement of antagonist muscle co-activation remains unclear. Bautmans et al. (2011) studied Mm. Biceps and Triceps Brachii activation in 64 apparently healthy elderly (80 ± 6 years) and 60 young (26 ± 3 years) subjects, during a simple RT-test (moving a finger using standardized elbow-extension from one push button to another following a visual stimulus). RT was divided in pre-movement-time (PMT, time for stimulus processing) and movement-time (MT, time for motor response completion). The study indicates that RT performance was significantly worse in elderly compared to young; the slowing was more pronounced for movement time than pre-movement time. Elderly subjects showed significantly higher antagonist muscle co-activation during the pre-movement time phase, which was significantly related to worse movement and reaction times ($p<0.01$). Also, during movement time phase, antagonist muscle co-activation was similar for both age groups. The study concluded that increased antagonist muscle co-activation in elderly persons occur in an early phase, already before the start of the movement. The findings provide further understanding of the underlying mechanisms of age-related slowing of *human motor performance*.

Chung et al. (2010) investigated the effect of age and two keypad types (physical keypad and touch screen) on the usability of numeric entry tasks. Twenty four subjects (12 young adults 23-33 years old and 12 older adults 65-76 years old) performed three types of entry tasks. Chung et al. (2010) noticed that the mean entry time per unit stroke of the young adults was significantly smaller than that of the older adults. The older adults had significantly different mean entry times per unit stroke on the two keypad types. Also, the error rates between young and old adults were significantly different for the touch screen keypad. The subjective ratings showed that the participants preferred the touch-screen keypad to the physical keypad. The results of the study showed that the older adults preferred the touch-screen keypad and could operate more quickly, and that tactile feedback is needed for the touch-screen keypad to increase input accuracy. *The study suggests that the results can be applied when designing different information technology products to input numbers using one hand.* The use of computer controlled devices is constantly increasing. At the same time the population of the industrialized world is aging. Lindberg et al. (2006) investigated the speed with which users of different ages can find a specific computer icon from a group of others. The results show that *search performance* slows with age. However, individual variability in search performance was very high within all age groups. The study suggests that icon used in graphical user interfaces should be at least about 0.7 cm at a viewing distance of 40 cm, for the majority of users to be able to perform their computerized tasks with relative ease. Also, the study concluded that the inter-icon spacing should be moderate, preferably about the same as the icon size and ideally user interfaces should be adaptable to individual user needs and preferences.

Although connections between cognitive deficits and age-associated brain differences have been elucidated, relationships with motor performance are less understood. Seidler et al. (2010) review age-related brain differences and motor deficits in older adults in addition to cognition-action theories. Age related atrophy of the motor cortical regions and corpus callosum may precipitate or coincide with motor declines such as balance and gait deficits, coordination deficits and movement slowing. The study concluded that in general, older adults exhibit involvement of more widespread brain regions for motor control than young adults. Goldhammer et al. (2010) investigates the effects of intelligence, perceptual speed and age on intraindividual growth in attentional speed and attentional accuracy over the course of a 6-minute testing session. The study concluded that the intelligence was not associated with the ability to learn to perform the attention task quickly and accurately. Also, age differences were mainly related to baseline performance. Results indicate that the concurrent performance aspects, speed and accuracy, are distinct in the shape of growth. The global-speed and the specific-gain/loss hypotheses have been dominant theoretical frameworks in the literature on cognitive development and aging (Span et al., 2004). Few attempts have been made to explicitly assess the predictive power of the two frameworks against each other. Span et al. (2004) evaluated the extent to which age changes in performance in executive function tasks (involving response selection, response suppression, working memory and adaptive control) depend on age-related changes in global information processing speed. The study used sample consisted of children, adolescents, adults and seniors. The analysis revealed a mixed pattern of results. Controlling for global speed removed the child vs. adult differences in the speed of responding on the executive function tasks but the senior vs. adult differences remained. The study suggest that the effects of advancing age on the speed of responding are mediated by a global mechanism during childhood but during senescence the efficiency of executive functioning seems particularly vulnerable to the effects of age.

The population of the developed countries is becoming older while computer use is affecting increasingly wide aspect of life (Hawthorn, 2000). It is increasingly important that interface designs make software accessible to older adults. The study noticed that there is almost no research on what makes an interface usable for older adults. Hawthorn (2000) reviews the findings on the effects of age on relevant abilities and uses this information to provide suggestions to consider when designing interfaces for older users. *The study concludes with indications of the needed research in the area of interface design for older users.* Kang and Yoon (2008) observed the behavior of younger adults (20-29 years old) and middle-aged adults (46-59 years old) interacting with complicated electronic devices. The study examined various aspects of interaction behaviors in terms of performance, strategies, error consequences, physical operation methods and workload. The analysis of age-related differences included differences in background knowledge. The results revealed that differences in age meaningfully affected the observed error frequency, the number of interaction steps, the rigidity of exploration, the success of physical operation methods and subjective perception of temporal demand and performance. In contrast, trial-and-error behavior and frustration levels were influenced by background knowledge rather than age. *The literature review on the effects of age on human performance indicates the need of separate interface designs for various age group individuals. It is also observed from the literature that the cognitive and motor performances of peoples vary with the age. Last but not least, the literature on effects of sex gender on human-performance is reviewed in the following section.*

2.4 Effects of Sex on Human Performance

Today's world is striving for providing equal employment opportunity to both the sex i.e. males and females in all walks of life. However, from the literature reviewed it appears that relatively fewer studies have been conducted to investigate the effect of sex on human performance. The largest average differences in cognitive performance derive from spatial tasks (Contreras et al., 2012; Rahman et al., 2005; Richardson and Tomasulo, 2011 and Rilea, 2008). It is observed that analyses performed to date have not been able to satisfactorily explain this difference in performance. Frequently, the sex variable is considered a casual factor. However, sex is a broad category that entails so many confounding factors that it is nearly impossible to consider it as a casual factor. Contreras et al. (2012) explained sex differences in spatial task performance in terms of sex differences in lower-level cognitive processes. The study identified the psychological variables that account for differences in spatial tasks due to sex of the sample.

The physical characteristics affect the ability to perform a task more in women than in men. There should be considerations to gender differences in the design of machines and tools (Bylund and Burstrom, 2006). Trent and Davies (2012) noticed that there are inherent sex differences in healthy individuals across a number of neurobiological domains (including brain structure, neurochemistry and cognition). Hazlett et al. (2010) examined the main and interactive effects of age and sex on relative glucose metabolic rate (rGMR) within grey matter of 39 cortical brodmann areas (BA) and the cingulated gyrus during a verbal memory task in 70 healthy normal adults, aged 20-87 years. Women showed significantly greater age-related rGMR decline in left cingulated gyrus than men. The results of the study suggest that both age-related metabolic decline and sex differences within frontal regions are more marked in medial frontal and cingulated areas, consistent with some age-related patterns of affective and cognitive change.

Jimenez- Jimenez et al. (2011) observed that the basic motor performance is influenced by gender and deteriorates with age. Godard and Fiori (2010) determine the influence of sex on hemispheric asymmetry and cooperation in a face recognition task. The study used a masked priming paradigm in which the prime stimulus was centrally presented. Fifty two right handed students (26 men and 26 women) participated in the experiment, in which accuracy (percentage of correct responses) and reaction times (RTs in ms) were measured. Although accuracy data showed that the percentage of correct recognition was equivalent in men and women, men's RTs were longer than women's in all conditions. Accuracy and RTs showed that men are more strongly lateralized than women, with right hemispheric dominance. The results of the study suggest that men are as good at face recognition as women, but there are functional differences in the two sexes. A number of other researchers have evaluated the effects of sex on various human performances (Alexander and Evardone, 2008; Hernandez et al., 2012 and Penton-Voak et al., 2007).

Huang and Wang (2010) investigated how task domain moderated sex differences in framing effects. Five hundred and eighty six participants (63.3% female) were randomly assigned to different frame valences (i.e., positive vs. negative) and different task domains (i.e., life-death vs. money vs. time). Results showed that in the life-death domain, females exhibited stronger responses to negative frames. In the monetary domain, males showed a greater response to negative frames. In the time domain, the pattern of sex differences were inconsistent across different framing tasks such that in the goal framing task, females were more willing to take actions under negative frames while males were just the opposite; in the risk-choice task, female were more inclined to take risk under positive frames while males did not show significant framing effects. Also, the results indicated that the framing effect is sex-specific, varying according to the gender role in different task domains. Huang and Wang (2010) research highlights the necessity to distinguish, rather than combine, individual judgments and decision-makings in different task domains. Hancock and Rausch (2010) examined the interactive effects of sex, age and interval duration on individual's time perception accuracy. The study engaged participants in the duration production task and subsequently completed questionnaires designed to elicit their temporal attitude. The overall group of 100 individuals was divided evenly between the sexes. Five groups each composed of 10 males and 10 females were divided by decades of age ranging from 20 to 69 years old. Analyses of the production results indicated significant influence for the sex of the participants. Pearman (2009) designed a study to explore the relationships between sex, personality and basic cognitive processes. It was noticed that female positively predicted the processing speeds. In addition, there was a sex versus conscientiousness interaction for processing speed in which females high in conscientiousness were significantly faster than males high in conscientiousness.

In some situations, memory is enhanced by stressful experience, while in others, it is impaired. The specific components of the stress-response that may result in these differing effects remain unclear. The result of a study conducted by Buchanan and Tranel (2009) provide evidence that cortisol is a primary effector in the stress-induced memory retrieval deficit. At the same time, stress can enhance memory retrieval performance, especially for emotional stimuli, when the cortisol response is absent. Certain cognitive processes, including spatial ability, decline with normal aging. Spatial ability is also a cognitive domain with robust sex differences typically favoring males. The findings of Driscoll et al. (2005) indicate that the persistence of male spatial advantage may be related to circulating testosterone, but not cortisol levels, and independent of generalized age-related cognitive decline. Espinosa-Fernandez et al. (2003) carried out a study in which age and gender differences were studied in the performance of an empty interval production task. The duration of these intervals was 10s, 1 and 5 minutes. The sample taken in the study was made up of 140 subjects, half male and half female, in seven different age groups from 8 70 years old. With regard to gender the study concluded that there was a greater underproduction of longer intervals (1 and 5 minutes) for women. Alexander et al. (2002) measured memory for object location relative both to veridical center (left versus right visual hemispace) and to eccentricity (central versus peripheral objects), in 26 males and 25 females, using memory location task. The study explored that, in both sexes, memory for object locations was better for peripherally located objects than for centrally located objects. In contrast to similarities in female and male task performance, females but not males showed better recovery of object locations in the right compared to the left visual hemispace. Moreover, memory for object locations in the right hemispace was associated with mirror-tracing performance in women but not in men. The study data suggest that the processing of object features and object identification in the left cerebral hemisphere may include processing of spatial information that may contribute to superior object location memory in females relative to males.

The unclear picture of the sex difference in color preference might result from personality variations (He et al., 2011). Reports of sex differences in way finding have typically used paradigms sensitive to the female advantage or sensitive to the male advantage (Andersen et al., 2012). On the basis of the neural efficiency concept of human intelligence-which suggests a more efficient use of the cortex (or even the brain) in brighter individuals- Neubauer and Fink (2003) analyzed the role of sex and task complexity as possible moderating variables in the relationship between cortical activation and psychometric intelligence. It was noticed that cortical activation increases with increasing task complexity. Furthermore, the study suggests that the males were more likely to produce cortical activation patterns, whereas in females no significant differences were found. Women typically outperform men on episodic memory and verbal fluency tasks, whereas men tend to excel on visuospatial tasks. As the vast majority of individuals are right-handed (RH), sex differences in the cognitive literature reflect laterality-specific patterns for RH individuals. Thilers et al. (2007) examined the magnitude of cognitive sex differences as a function of hand dominance in samples of RH and non-RH individuals. The results of the study showed the sex differences in the RH group, whereas these differences were unreliable in the non-RH group.

The literature reviewed as above, however, indicated that the effect of sex on performance in the context of human-CNC machine interface (HCMI) is yet to find a place for being investigated. In light of the fact that the number of females performing in computer interface environments is excessively on the increase at a phenomenal rate and the sex related differences are well documented, it is getting very important and crucial to investigate the effect of sex, an important organismic factor in the HCMI environment.

III. Interface Design Methodology

As evident from preceding discussion, the effects of anthropometric considerations like machine panel height, panel angle and working distance on human performance particularly in the context of human-CNC machine interface (HCMI) are still not fully understood and thus, there exists a wide scope to investigate these effects. Accordingly, the human-CNC machine interface design methodology for the present work was formulated. There has been a rapid growth in the use of CNC machines. These machines have entered virtually every area of our life and work environments. With the CNC machine applications getting more widespread at the global level, the musculoskeletal problems associated with these machines have also been generating more concern. The automated technologies are getting much more popular day by day. However, the pace of research in the field of human-CNC machine interaction environment has been rather slow in comparison to the growth rate of CNC machines not only in developed nations but also in developing countries like India. Human problems associated with the HCMI 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 exponential growth in the use of CNC machines has brought many subtle issues/problems pertaining to their effective utilization from human efficiency and comfort view points. 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 CNC machine tools.

3.1 Experimental Design

In the designed studies, human performances can be measured in terms of search time, motor action time and applied force on the CNC machine panel keys. The search time, motor action time and applied force features could be selected in the light of previous researches (Chen and Chiang, 2011; Bedny and Karwowski, 2006; Layer et al., 2009; Bothell, 2004 and Bergmann et al., 2011). A pilot study could be conducted to determine the discrete levels of the HCMI parameters that could help to operate a CNC machine tool, 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. To select an orthogonal array for the experiments, the total degrees of freedom (df) are computed first. For example, a *three level* design parameter counts for *two* degrees of freedom. The degrees of freedom associated with the *interaction* between two design parameters are given by the *product* of the degrees of freedom of the two concerned design parameters. Once the required degrees of freedom are known, the next step is to select an appropriate orthogonal array to fit the specific task. Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the design parameters (Goel et al., 2011). 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^{13}) 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 3^3 factorial design. The three parameters (A, B and C) and three, two-way interactions (AxB, AxC and BxC) will need 18 degrees of freedom and will occupy 18/2 = 9 of the 13 columns of an L_{27} OA. The remaining four columns of the L_{27} OA are treated as dummy parameters.

Search time, motor action time and applied force acts as response variables to evaluate the CNC machine operator's performance. A full factorial design (based on L_{27} orthogonal array) of experiments consisting of 27 (3^3) experiments is used to collect data for human performance in terms of search time, motor action time and applied force. The collected data would be analyzed using grey relational analysis and analysis of variance (ANOVA) and F-test. These methods are described below:

3.1.1 Grey Relational Analysis

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 pre-processing 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 pre-processing and determination of grey relational coefficient and grey relational grade are described as follows:

3.1.1.1 Signal-to-Noise Ratio

Taguchi method is one of the simplest and effective approaches for parameter design and experimental planning (Ross, 1988). 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 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 ratio (Siddiquee et al., 2010 and Goel et al., 2011) with a "the lower the better" characteristic can be expressed as:

$$\eta_{ij} = -10 \log\left(\frac{1}{n}\sum_{j=1}^{n} y_{ij}^2\right) \quad (1)$$

The S/N ratio with a "the nominal the better" characteristic can be expressed as:

$$\eta_{ij} = -10 \log\left(\frac{1}{ns}\sum_{j=1}^{n} y_{ij}^2\right) \quad (2)$$

The S/N ratio with a "the higher the better" characteristic can be expressed as:

$$\eta_{ij} = -10 \log\left(\frac{1}{n}\sum_{j=1}^{n} \frac{1}{y_{ij}^2}\right) \quad (3)$$

Where y_{ij} is the '*i*th' experiment at the '*j*th' test, '*n*' is the total number of the tests and 's' is the standard deviation. The S/N ratios are expressed on a *decibel scale*. Regardless of category of the performance characteristics, a greater *'η'* value corresponds to a better performance.

3.1.1.2 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" (Siddiquee et al., 2010 and Goel et.al, 2011). 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'*. The normalization can be done from *three* different approaches (Khan et al., 2010). If the target value of original sequence is infinite, then it has a characteristic of "the higher the better". The original sequence can be normalized as follows (Khan et al., 2010):

$$x_i^*(k) = \frac{x_i^*(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \quad (4)$$

If the expectancy is "the lower the better", then the original sequence should be normalized as follows:

$$x_i^*(k) = \frac{max\, x_i^0(k) - x_i^0(k)}{max\, x_i^0(k) - min\, x_i^0(k)} \quad (5)$$

However, if there is a definite target value to be achieved, the original sequence will be normalized in the form:

$$x_i^*(k) = 1 - \frac{|x_i^0(k) - x^0|}{\max x_i^0(k) - x^0} \quad (6)$$

or the original sequence can be simply normalized by the most basic methodology, i.e. let the values of original sequence be divided by the first value of sequence:

$$x_i^*(k) = \frac{x_i^0(k)}{x_i^0(1)} \quad (7)$$

where $x_i^*(k)$ is the value after grey relation generation (data pre-processing), $max\, x_i^0(k)$ is the largest value $x_i^0(k)$, $min\, x_i^0(k)$ is the smallest value of $x_i^0(k)$ and x^0 is the desired value.

3.1.1.3 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 (Khan et al., 2010):

$$\xi_i(k) = \frac{\Delta_{min} + \varsigma.\Delta_{max}}{\Delta_{0i\,(k)} + \varsigma.\Delta_{max}} \quad (8)$$

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

$\Delta_{0i\,(k)} = \| x_0^*(k) - x_i^*(k) \|$,

$\Delta_{max} = max_{\forall j \varepsilon i}\, max_{\forall k} \| x_0^*(k) - x_j^*(k) \|$,

$\Delta_{min} = min_{\forall j \varepsilon i}\, min_{\forall k} \| x_0^*(k) - x_j^*(k) \|$

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

After obtaining the grey relational coefficient, its average is calculated to obtain the grey relational grade. The grey relational grade is expressed as follows (Khan et al., 2010):

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (9)$$

However, in actual application the effect of each factor on the system is not exactly same; Equation 5.9 can be modified as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} w_k.\xi_i(k) \quad ; \quad \sum_{k=1}^{n} w_k = 1 \quad (10)$$

where w_k represents the normalized weighing value of factor '*k*'. Given the same weights, Equations 9 and 10 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 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. Therefore, if a particular comparability sequence is more important than the other comparability sequence to the reference sequence, then the grey relational grade for that comparability sequence and reference sequence will be higher than other grey relational grades (Yang et al., 2006). In this work, the importance of both the comparability sequence and reference sequence is treated as equal.

3.1.2 Analysis of Variance (ANOVA) and F-test

The purpose of ANOVA and F-test is to find which individual factor and interaction between them significantly affect the multi-performance characteristic. This statistical analysis is based on the variance, the degree of freedom, the sum of squares, the mean square, the F-ratio, the P-value and the percentage of contribution to the total variation (Ma et al., 2007). The detailed procedure for calculating parameters pertaining to ANOVA is described in Samant et al. (2008). It is proposed to carry out analysis of variance (ANOVA), interaction effect analysis and various models adequacy tests using the *Design Expert Software.*

3.2 Stimuli and the Experimental Task

Stimuli material should be available to the subjects in the form of colored light emitting diodes (LEDs) fixed on an adjustable height display board. The colors for visual stimuli could be *red, blue, yellow, white and green.* So far as the availability of visual stimuli during the task is concerned, the LEDs 'on' and 'off' positions should be controlled by the experimenter. The LEDs through a switchboard are connected to one of the channels (Channel-2) of the oscilloscope. A designed CNC machine panel and working platform (described later) could be used for the studies. The panel is joined with *'load cells'* (piezo-electric sensors), and the assembly is fixed on an adjustable 'height' and 'angle' platform (Sanders and McCormick, 1992). The variable working distance (Chikhaoui and Pigot, 2010) could be incorporated with the help of colored strips pasted on the ground in front of assembled platform. The machine panel had two lead connections. First is with one of the channels (Channel-1) of the oscilloscope and the second, with the visual display unit (VDU) monitor through central processing unit (CPU). During the experimentation, subjects stand according to the selected HCMI parameters combination in front of the working platform (Maldonado-Macias et al., 2009) with index finger of the right hand placed (for recording search time) on the CNC machine panel 15 centimeters away (Chikhaoui and Pigot, 2010) from the panel keys (used for recording motor action time and applied force). Left hand of the subjects remained free along the side. The subjects were required to respond to the visual signal (in the form of particular color LED on-position for a short period), provided by the experimenter through switchboard. The signal at the moment of 'LED-ON' is recorded through the oscilloscope. Subjects were asked to search, without lifting right hand index finger, the CNC machine panel where the key, similar to first *alphabet* of the activated color stimuli exists (i.e. for *Green* color the first alphabet is 'G'). As soon as the required '*key'* is '*searched'*, the subject lifts the index finger and presses the key. The signal at the moment of *'finger-lift'* is recorded through the oscilloscope. The time difference in milliseconds, between visual-stimuli and finger-lift is saved as the *'search time'* (cognitive time).To ensure the correct execution of the task (matching 'key search and press' on the basis of supplied visual signal), a *software* in *C++* language was developed, which also helped to get *'zero error'* experimental results. The software was loaded on the computer system connected to self-designed CNC machine panel assembly. As a particular alphabet (out of five R, B, Y, W and G only) key is pressed (on the basis of visual signal) on the machine panel, the loaded software displays a full VDU screen image (square shape) of the color whose first alphabet is pressed (i.e. if the subject presses 'R', the software displays a full VDU screen square 'RED' shaded image). This ultimately ensures the correct execution of the task. For incorrect execution the task was repeated in random order. The software do not display any image if a key other than the five above mentioned alphabets, is pressed. Two more signals at the moment of *'searched key pressing'* were recorded, first on x-axis of the oscilloscope and the second on y-axis. Through x-axis, the time difference in milliseconds between 'finger-lift' and 'searched key press' moments was saved as *'motor action time'*. When the searched key was pressed, the *'applied force'* on the panel key in millivolts was recorded through the y-axis of the oscilloscope. Each subject executes the same task against five (Red, Blue, Yellow, White and Green) randomly supplied visual stimuli. The experiment should be uniform for all participants. Finally, the average of, five human-performances in terms of '*search time', 'motor action time' and 'applied force'* , could be recorded for analysis. For *experimental validation*, movie of each subject could be recorded through a video camera. The video camera should be used to record and take photos of the subject to identify stress full body postures during the CNC machine operation (Maldonado-Macias et al., 2009).

3.3 Experimental Set-Up

As stated earlier, human performance could be measured in terms of search time, motor action time and applied force on the machine panel keys. All experiments should be performed in a simulated environment chamber.

Two sample studies as described were performed to explain the designed experimental set-up. The *temperature* of the experiment chamber (Sanders and McCormick, 1992) was approximately 23 ± 2 degree Celsius measured through wall temperature indicator (model: me DTI 4001). *Reflection* of the light from windows and door was eliminated through proper covering. When the chamber was closed, the cubicle got *acoustically sealed* from the outside environment. The *illumination* level throughout all the experimental sessions (OSHA, 2011 and Sanders and McCormic, 1992) was maintained at 590 ± 10 lux. This level of luminance was monitored through a digital lux meter (model: LT Lutron LX-101). The relative *humidity* level of the experiment chamber (Sanders and McCormic, 1992) was approximately 77 ± 3 percent measured through 'hair hygrometer' (model: Ekbote HAIR Hygrometer). *Sound* level throughout all the experimental sessions (OSHA, 2011 and Sanders and McCormic, 1992) was approximately 52 ± 3 dBA measured through sound level meter (model: LT Lutron SL-4001). Measuring tape, digital vernier caliper and weighing machine were used to measure various anthropometric characteristics of the subjects. The *search time*, *motor action time* and *applied force* was measured through 2-Channel Oscilloscope (model: DS 1062 C; make: Rigol Digital Oscilloscope Ultrazoom; specification: 60 MHz 400 MSa/s). The positions of the indigenously designed CNC machine panel, subject and other peripheral devices were maintained as portrayed in the schematic diagram (Figure 1).

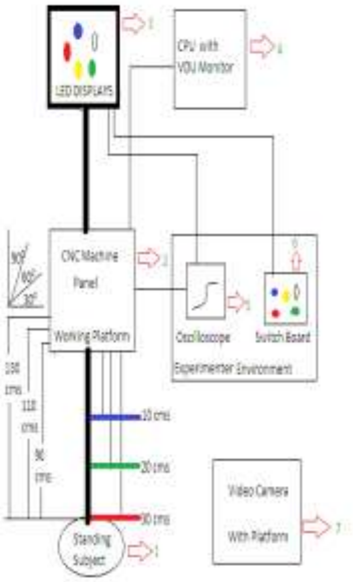

Figure 1 : Schematic diagram of the set-up employed in the sample experimental investigations

As shown in the Figures 1 and 2, the standing subject (item 1 of Figure 1) in front of CNC machine panel can maintain any working distance (10/20/30 cm) according to colored strips.

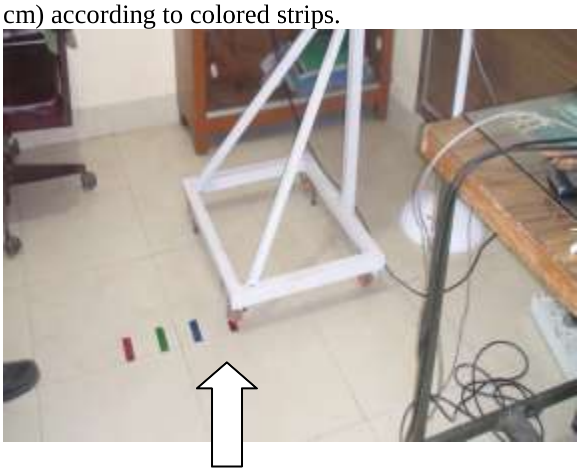

Figure 2: Working distances shown with colored strips

The working platform (item 2 of Figure 1) can be adjusted at any (90/110/130 cm or else) height through adjustable screw as depicted in Figure 3.

Figure 3: CNC machine panel height adjustment system

The CNC machine panel (item 2 of Figure 1) can also be adjusted at any (30/60/90 degrees or else) angle through adjustable mechanism as shown in Figure 4.

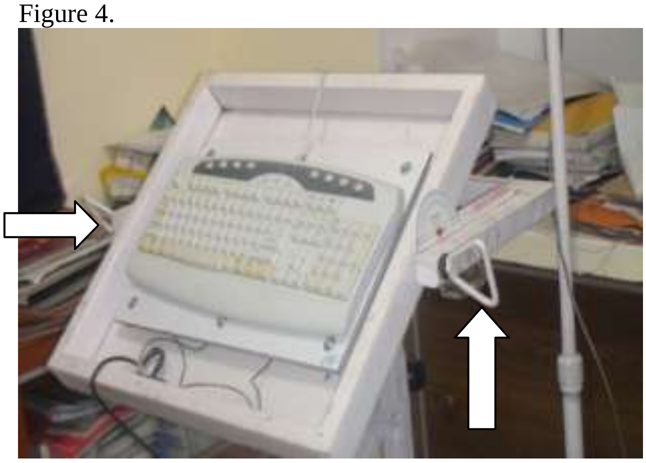

Figure 4: CNC machine panel angle adjustment mechanism

The item 3 of the Figure 1 provides colored visual stimuli. The provision of variable height visual signal with colored LED board is shown in Figure 5.

Figure 5 : Variable height colored LEDs board

The item 4 of Figure 1 indicates an environment where a CPU and VDU monitor was stationed for ensuring correct execution of the experimental task. Figure 18 shows a CPU and VDU monitor arrangement displaying green square image when subject on the basis of activated green LED visual signal, presses alphabet 'G' on the CNC machine panel.

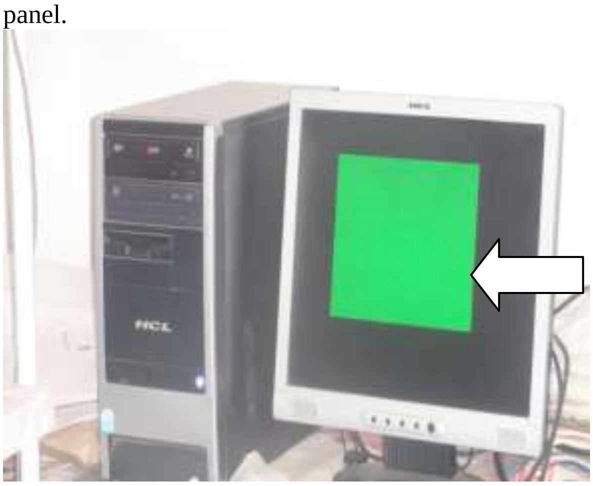

Figure 6: Displaying a full VDU screen square filled with green color in response to supplied green visual stimuli

Items 5 and 6 of Figure 1 are showing experimenter environment with a 2-Channel oscilloscope for recording human performance and a switch board for providing visual stimuli, respectively. The Figure 7 depicts the arrangements of oscilloscope and switch board.

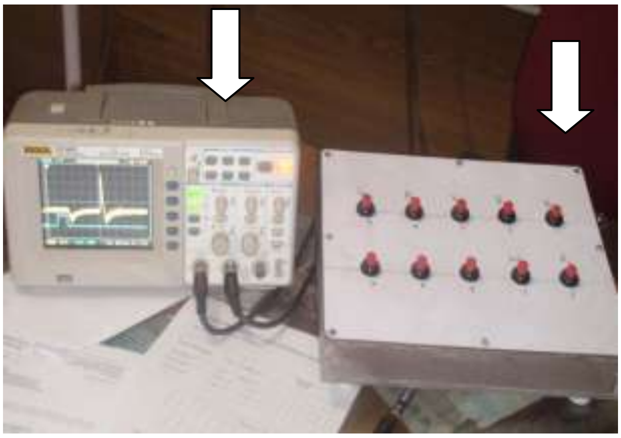

Figure 7: Oscilloscope and switch board positions

The item 7 of Figure 1 shows location where from the movie of the subjects performing the task was shot. Figure 8 indicates the position where a SONY Digital Handycam video camera was stationed.

Figure 8: Showing stand where camera was fixed

Figure 9 shows a male subject with his index finger placed at a position. As the subject lifts the finger, search time signal is recorded through oscilloscope (Sample study I).

Figure 9 : Male subject waiting for visual stimuli

Figure 10 depicts the same male subject performing motor action on the basis of supplied visual

Figure 10: Male subject performing motor action

stimuli. With this execution, motor action time and applied force signals are recorded through the oscilloscope. Figure 11 shows a female subject with her index finger placed at a position. As the

Figure 11: Female subject waiting for visual stimuli

subject lifts the finger, search time signal is recorded through oscilloscope (Sample study II). Figure 12 depicts the same female subject performing motor action on the basis of supplied visual

Figure 12: Female subject performing motor action

stimuli. With this execution, motor action time and applied force signals are recorded through the oscilloscope.

Figure 13 shows the load cells (piezo-electric sensors) arrangement which was used to fix a keyboard. Finally this structure was assembled with a self fabricated adjustable panel, to give a shape similar to a CNC machine panel.

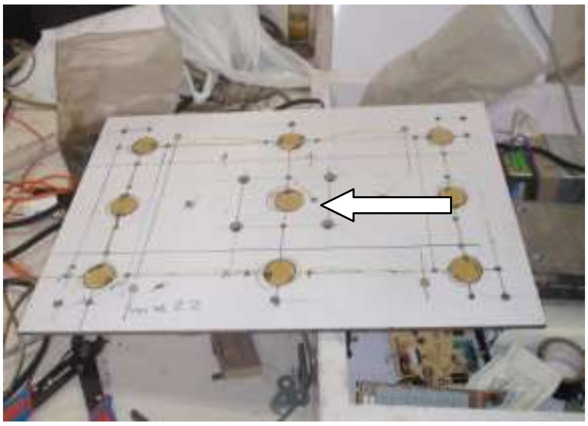

Figure 13: Load cells (piezo-electric sensors) fixed on mica-sheet

3.4 General Experimental Procedure

Before the start of sample experimentation, a pilot study was undertaken. This helped in pre-planning the details of experimental sessions and in checking the suitability of the observation sheet designed for collecting the experimental data. Following preparatory steps were undertaken before actually conducting the experiments:

(i) Each subject selected for the task was briefed about the objective of the experiment.
(ii) A training session was organized for each subject in order to familiarize them with the designed CNC machine panel. Some trial runs for the experiment were undertaken for training purpose.

After the subject had stand in front of machine panel according to the selected HCMI parameters and all the instructions imparted, the following steps were taken in the order, for both training as well as actual experimental sessions:

(a) The subject was required to keep their right hand index finger on a pre-position location of the machine panel.
(b) Through switchboard, colored visual stimuli in a randomized manner were presented to the subject by experimenter during different sessions.
(c) The subject responded by lifting the same index finger and pressing the required key at the CNC machine panel. The task was repeated five (for red, blue, yellow, white and green visual signal) times for each subject.
(d) The human-performance in terms of search time, motor action time and applied force on the key of machine panel was recorded through oscilloscope against each visual signal (Figure 14).
(e) Average of five performances was considered for the result analysis.

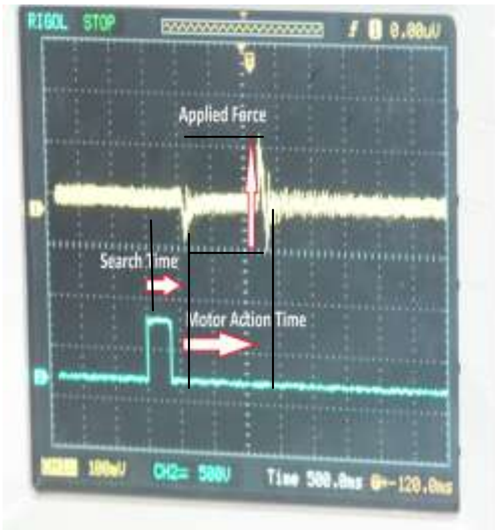

Figure 14: Recording of search time, motor action time and applied force through 2-channel Oscilloscope

IV. 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 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 work place. 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 from the prevention and management of MSDs show improvement of work environment, the relation between the labor and management, productivity and decrease in lost work days. 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 kind 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 (Danuta, 2010).

V. Conclusions

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

i) *Re-evaluation* of the existing HCMI work environment from the impact of anthropometric factors point of view is needed. It appears, irrespective of age and gender, the variables *CNC machine panel height, panel angle and working distance* offer a more efficient working environment.

ii) It is explored that panel operated machine systems in general and CNC machine systems in particular, should be *redesigned* so as to have an *operating panel* with the *adjustments of both height and angle*.

iii) It is observed that various ergonomic databases should be generated for the effective and efficient utilization of a HCMI system. The databases should be in terms of CNC machine panel height, panel angle and working distance.

iv) It appears that relatively few studies have been undertaken in the past on the *gender and age* comparisons in human-machine interaction environment, specifically in the area of human-CNC machine interface environment. Present work indicated that the female operators are *more efficient* than their male counterpart in terms of *motor action* and also they exert *less force* on the panel keys. However, male operators as compared to their female counterpart are better in *search related task* on CNC machine panel. Furthermore, it is explored that the *upper age* group male operators require *higher motor action* time. These findings would help the system designers to allocate *appropriate task* to *males of various* ages and *female* CNC machine operators.

v) Finally it is observed that the *force applied* on the CNC machine panel keys *decreases* as age of male operator increases. This finding provides an important ergonomic database for the manufacturers of *touch screen CNC machine panels*.

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