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Optimal Posture Prediction in Brick Stacking Operation for Reducing Ergonomic Risk Factor

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Abstract— Ergonomic risk factors are vital for posture prediction of human, working in manual assembly is founded on the human movements at each joint to decrease energy level and fatigue level of the worker. In this study a simple measure of human performance is introduced that permits the mathematical model to assess the cost functions. Here human is modeled as a structure of 20 DOF. The necessary procedure is the evaluation of the performance in the system of cost factors. Here two main cost factors are considered as discomfort factor and energy expenditure rate in different limbs movement. The basic objective is to optimize the limb movements to the cost factors. The above procedure is verified through a example case of fly ash bricks plant. Here two workers are stacking bricks in stacking pan. A Multi Objective Optimization (MOO) technique is utilized for the prediction of posture, in which cost factors are minimalized, ultimately reduced level of ergonomic risk factor.

keywords: ergonomics; ergonomic risk factor; human posture; discomfort factor; energy factor; optimization.

I. INTRODUCTION

Ergonomics is commonly utilized to learn the relation between workers and their surroundings. This inspects the reaction of the workers while performing the work. In the meantime, the merits and demerits of the worker are also seen to have more beneficial result while doing the work. For the wellness and security of the worker the work stress intensity should be looked at. Hence the study of ergonomics is mainly required to keep the worker safe and healthy for successful result. The necessary idea of risk and risk factors are utilized for the knowledge of safety in applied ergonomics, where different ergonomic risk factors are taken to review the work area safety like unnecessary force, inconvenient and repetitive body movements.

The computer hardware's and necessary software's are used for modelling and simulation of ergonomic analysis of relationship of machine with human beings. The price of manufacturing prototypes is reduced by incorporating virtual surroundings. It benefits the process by changing body arrangement location and condition of work as well as simulations. The virtual human model for its body arrangement response is simulated by ergonomist for a specific environment. The design cost and cycle time can be reduced by utilization of virtual human model. (Badler, 1997; Honglun et.al., 2007).

By varying the limb's positions, the capacity of the subject is increased. The thought is to get few information measures to reduce energy utilization because of the worker's limb movements. The discomfort level also has to be minimized relying on the limb's movement starting first through neutral position. Because of this a standard human model simulation is carried out. The primary focus is to examine model performance relating to discomfort factor, because of limb's movements and also needed energy for this.

Commonly, the risk factors are also the part of the work environment. Risk factors means the chance of being harmed and the effect of harm are the parts of the plane risk indulged, and coverage time gap of the worker. The absence of injuries does not imply that there is no risk.

Risk factor is termed as the thing which causes the chance of getting injuries to the musculoskeletal structure. Literature supported through applied ergonomics gives a small list of general risk factors getting indulged through different occupation and work places. The link between the exposures of risk factors and the periods of musculoskeletal damage risk is not stated easily. Li et.al. (1999) describes the reason of MSD are load, posture, personal factor and vibration.

Risk factors are grouped into three areas, these are biomechanical exposure, psychosocial stressors and individual risk factors. The initial biomechanical exposures classify factors such as miserable working surroundings like intense temperature zone, extreme vibration condition and biomechanical exposures namely or like motion repetitions, great physical effort and departure from neutral body alignment. The second type psychosocial stressors during working include factors such as high-perceived works stress, low-perceived societal support, low perceived job control, and pressure due to timeline. The third type specific factors cover age, gender, undesirable stress, stomach responses, substandard relaxation period and the supplementary domestic workload. Chen et.al. 2000 verified the movement strategy in manual handling jobs in industries depends on the fatigue state of muscle.

As per Jaffar et al. 2011 common risk factors for musculoskeletal disorder are Excessive Force, Repetition of motion, excess vibration, Awkward Posture, Static Loading, Contact Stress, Extreme environment Temperature.

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Excessive force defines the physical attempt that is required for performing a task or continuing to manage the tools. Due to excessive force the effects are muscular stresses, pressure on the tendons and joints which are connected with injury risk at different positions of shoulder, neck, lower back, forearm, wrist, and hand.

Repetition of motion means using the same muscles continually without rest. The effects are strains in the tendons and the muscles connected in the through repetition of movements and the putting and soothing of the limit in space.

Awkward Posture means the human body joints are bends or twists more than limiting value or any muscles stretch done, outside a comfortable range of gesture. The effects of awkward posture results in sprains and strains in the wrist, neck, lower back and shoulder.

Vibration may be defined as any to and fro motion made by the body about an immovable position. The injury incurred to the body parts knocked by moderately low occurrence and failure of the body tissues due to continual resonance of the high energy vibration.

Static Loading maintains anybody position without change over a long period. This condition results in a combination of force, duration and posture.

Contact Stress means injury caused by hard and sharp object during grasping or manipulating the object. The effects are the injury caused by pressure to the nerves then tissues under the skin of wrist, palm and fingers after a hard or pointed thing is in connection with the skin.

Extreme Temperature means exciting hot or cold. The effects are cold causing trembling, concerned consciousness, widened pupils, and ventricular fibrillation; resulting in warmth caused heat fatigue, heat cramps and even heat stroke.

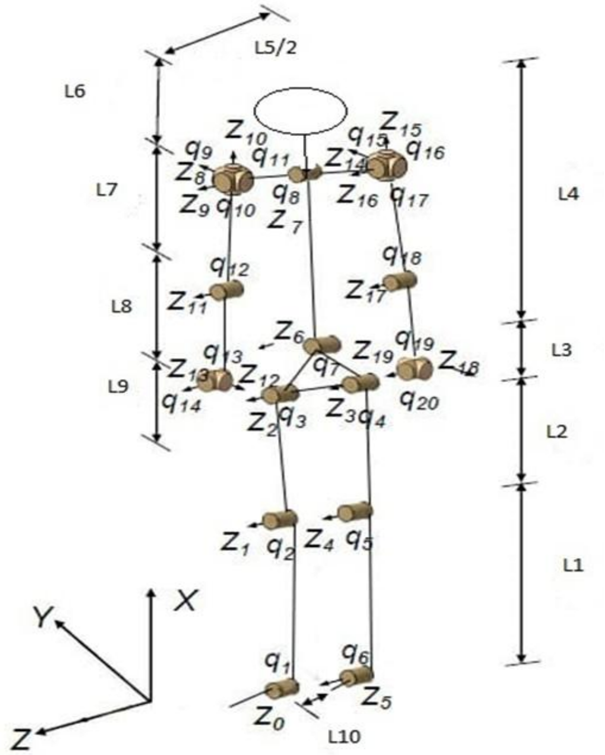
The development of musculoskeletal health problem at work is one of the most significant aims of ergonomics. Musculoskeletal disorder (MSD) is the disorder that includes the disorder involving muscles, nerves, tendons, ligaments, joints, cartilage, or spinal discs. MSDs are cumulative-type of disorder. In other word MSD's are a set of provocative indications which affects the parts such as the neck, back, arms or legs. Simoneau et.al. 1996 describes work-related musculoskeletal disorders (WMSD), defined as a division of musculoskeletal disorders (MSD) that arise out of professional exposures, may lead to work constraint, work-time loss, or as a result cause leave from work.

Nipun et.al. 2017 describes awkward posture is one of the main reasons of WMSDs, the study mainly focused on evaluating the risk points related with awkward postures while executing manual tasks in industrial applications,

In this paper we are considering a various ergonomic risk factors by minimizing the discomfort factor and energy expenditure factor for the subject by modeling a human body and optimizing these two objective cost functions and predict the posture.

II. MODELLING OF LIMBS:

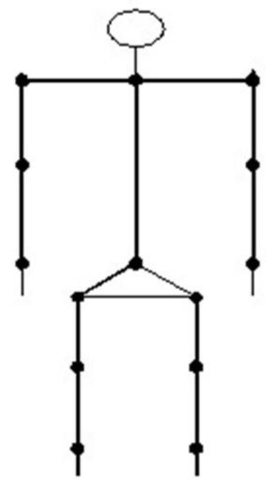
In this work a human is modelled as a number of rigid bodies (links) and joined with each other by revolute joints. This is described with 20 DOF as shown in figure-1. The parameters utilized in the model is shown in Table-1. In the human musculoskeletal system there are various joints are wrist, elbow, shoulder, trunk, hip, knee and ankle joint.



[Fig 1: The Modeling of human]

The usual joints of human musculoskeletal system are used with one DOF, two DOF or three DOF. Abduction or adduction, supination or pronation and flexion or extension are motions of the shoulder taken to be three DOF model. Abduction or adduction and flexion or extension are motion of wrist as two DOF model. Knee, trunk, elbow and spine are taken as single DOF having flexion or extension movement. Planter flexion or dorsal flexion are motion of ankle joint and taken as single DOF.

The neutral position which is the most suitable position defined when someone stands upright and the arm hangs vertically downward as shown in figure-2. It is considered to be the maximum comfortable positions as any movement from this position increases the energy level or the stress level.



[Fig 2 The Neutral Position of human]

Table-1 Showing the parameters along with position

Required Parameters					Positions		
DOF	θ_i	d_i	α_i	a_i	NEUTRAL POSITION	LL	UL
1	$-q_1$	0	0	L_1	0	-50	38
2	q_2	0	0	L_2	0	0	135
3	q_3	0	$-\pi$	0	0	-18	113
4	$-q_4$	0	0	L_1	0	-18	113
5	q_5	0	0	L_2	0	0	135
6	q_6	0	$-\pi$	0	0	-50	38
7	q_7	0	0	L_3	0	-19	56
8	q_8	0	0	0	0	-30	40
9	q_9	0	$\pi/2$	0	0	-60	170
10	$-q_{10}$	0	$\pi/2$	0	0	-18	80
11	q_{11}	0	$\pi/2$	-L7	0	-20	97
12	$-q_{12}$	0	$\pi/2$	$-L_8$	0	0	140
13	$-q_{13}$	0	$\pi/2$	0	0	-70	80
14	q_{14}	0	$\pi/2$	$-L_9$	0	-30	20
15	q_{15}	0	$\pi/2$	0	0	-60	170
16	$-q_{16}$	0	$\pi/2$	0	0	-18	80
17	q_{17}	0	$\pi/2$	-L7	0	-20	97
18	$-q_{18}$	0	$\pi/2$	$-L_8$	0	0	140
19	$-q_{19}$	0	$\pi/2$	0	0	-70	80
20	q_{20}	0	$\pi/2$	$-L_9$	0	-30	20

For simulation of model, DH method which is a standard technique of expression for the position and torque in robotics and biomechanics fields is used for this work. Accordingly, the required parameters for DH algorithm are chosen as in Table-1. For *n*-DOF human model, the necessary location vector can be explained in terms of joint variable as:

$$X = x(q) \qquad (1)$$

To find position of a particular segment subsequent multiplication of transformation matrices from one end to the required position can be calculated as:

$$^{0}T_n = {}^{0}T_1\,{}^{0}T_2 \cdots {}^{n-1}T_n = \begin{bmatrix} {}^{0}R_n(q) & x(q) \\ 0 & 1 \end{bmatrix} \qquad (2)$$

Modified D-H notation system (Khalil et.al., 1986 and 2002) is used to define the flexibility of each joint for movements. Each revolute joint having its individual coordinates written as q_i with its limits as upper limit (q_i^U) and lower limit (q_i^L). A set of generalized coordinates for representing the kinematic chain as $q = [q_1 \ldots q_i \ldots q_n]^T$.

III. OPTIMISATION FORMULATION:

The basic objective of this work is to find angles of different joints such that the finger will reach the target point. In this process 20 numbers of degree of freedom of the joints are there which gives different combinations of joint parameters to achieve the goal. Out of all these possible combinations the requirement is to find the optimize combination which will satisfy the condition of reaching the target point with in the respective limits of the joint parameter and also minimize the multiple performance measure.

Marler et al. (2004) describes multi objective optimization (MOO) is the procedure of optimizing methodically and concurrently an assembly of objective functions. For this case optimization technique, multi objective optimization (MOO) method is used for posture prediction. MOO method mathematically determined as follows:

$$\begin{aligned} &find: q \in R^{DOF} \\ &To\min imize: f(q) = [f_1(q) f_2(q) \ldots f_k(q)]^T \\ &Subject\ to:\ q_i(q) \le 0 i = 1,2,\ldots,m \\ &h_j(q) = oj = 1.2,\ldots,e \end{aligned} \qquad (3)$$

In the above equation k represents total number of objective cost functions, m represents total number of inequality constraints, h_j is the constraint, e represents total number of equality constraints, q ϵ E^{DOF} is the vector of design variables.

Discomfort function indicates increase in stress in the body parts as a function of CG of the chosen position to the neutral position. It is observed, the discomfort function of each joint in its neutral position is minimum and is increases when approaches to the limiting values of joint i.e. upper and lower limit. The discomfort of the subject increased when the joint parameters reach the near extreme position compared to neutral position. On the near limiting situations, the muscles of subject is stretched or compressed more compared to neutral position. The neutral position is the most comfortable position of the posture for a particular task. By changing the limb position from the neutral position comfort level reduces as per the stress developed in the muscle.

The change of position of cg from the neutral position to the total range of possible positions is an indicator of discomfort of that joint. Different DOF contribute different level of discomfort. Mathematically normalized position factor can be expressed as;

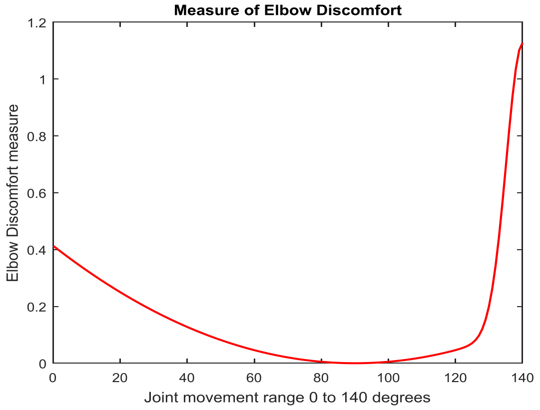
$$\Delta q_i^{norm} = \frac{q_i - q_i^N}{q_i^U - q_i^L}$$

The discomfort function depends upon normalized position factor, upper and lower limit of joints. The discomfort level is mathematically represented in Eq. (4) as in (Yang et al., 2004).

$$f_{discomfort} = \frac{1}{G} = \sum_{i=1}^{DOF}\left[\gamma_i\left(\Delta q_i^{norm}\right)^2 + G*QU_i + G*QL_i\right] \quad (4)$$

Discomfort function increases expressively as joint values approaches their limits as shown in figure-3 for knee joint. *QU* and *QL* are consequence terms compatibly to the upper and lower limit of the joint. γ_i is the weight factor for each joint. G is a constant which equals to 10^6. Δq_i^{norm} is the normalized position factor with respect to initial position (q_i), neutral position (q_i^N) with in the upper and lower limit.

Joint discomfort performance for knee joint shown graphically in figure-3 as an example. It is evident from the figure that joint discomfort at neutral position is minimum and it rises when approaches to upper limit and lower limits.



[Fig-3 Knee joint discomfort]

The more energy expenditure during one cycle of operation gradually leads to fatigue for the subject. The position of the center of gravity of the limbs with respect to the reference point gives variations in energy. In this work these two performance measures are considered for minimizing the combined performance measure for optimal value.

The total pace of energy expenditure, is expressed in Watts per Kilogram is denoted by E and is defined as follows:

$$\dot{E} = \dot{E_W} + \dot{E_M} + \dot{E_S} + \dot{E_B} \quad (5)$$

Where, E_W represents the muscle power, E_M represents the muscle heat rate, E_S represents the shortening heat rate of muscle and E_B represents the basal metabolic rate (BMR).

Muscle energy is defined as the dot product of torque (τ_i) and velocity (q_i) of each joint as described by Kim et al. (2005). So mathematically E_W cab be expressed as:

$$\dot{E_W} = \sum_{i=1}^{DOF}\left|\tau_i \dot{q_i}\right| \quad (6)$$

As described in the research work of Kim et al. (2005) and Anderson et al. (2001) it is nearly found to be proportional to the torque of each joint. The total mechanical power E_M is as follows:

$$\dot{E_M} \approx \sum_{i=1}^{DOF}\xi_i\left|\tau_i\right| \quad (7)$$

Where, ζ_i is represents the coefficient of maintenance heat rate taken at joint i,

The BMR is the metabolic rate of a human at rest. BMR can be model as:

$$\dot{E_B} = 0.685BW + 29.8 \quad (8)$$

BW represents the human body weight in kilogram.

The total energy expenditure rate is taken as the addition of the BMR and maintenance heat rate. The expression is given as below:

$$f_{energy} \approx \sum_{i=1}^{Dof}\xi_i\left|\gamma_i\right| + E_{B}. \quad (9)$$

So, for this case two objective function as described above are considered. To get the optimal posture, the optimizing condition should be solved. The above equation with respect to present problem can be written as follow

$$find : q \in R^{20}$$

$$\text{To minimize:} \quad f(q) = \begin{bmatrix} f_{discomfort} \\ f_{energy} \end{bmatrix}$$

$$\text{Subject to: } \left\|P(hand) - P(object)\right\| \leq \in$$

$$q_i^L \leq q_i \leq q_i^U \quad \text{i=1,2,....,20} \quad (10)$$

The multi objective formulation described above is used for the posture prediction of the lifting case using a case study in the next section.

IV. CASE STUDY

Discomfort function and energy expenditure function of a worker for this specific work was attained by means of the equations as in section-3. To assess the present model and its usefulness, two workers working in a local fly ash bricks manufacturing plant is considered. Two example cases were taken, for two workers moving in opposite direction to pick the bricks from the source to put in stacking pan. The movements are captured through camera and video clips are analyzed for posture constraints for all related points of each position.

The procedure of stacking is carried out by particular workers. Three hundred sixty bricks of sizes 22.86 mm X 7.62 mm X 12.7 mm and having weight 6.5 kg were organized in three loading pans of sizes 900 mm X 600 mm X 152.4 mm. The bricks stacking procedure is picturized in figure-4. At this point first worker of weight 68 Kg and 162.5 cm tall and second worker of weight 75 Kg and 175cm tall are engaged for the study. The first worker stacks the bricks in stacking pan A1, A2, A3 and the second worker stack in B1, B2, B3 respectively.

Stacking arrangement is described in our previous work Biswaranjan Rout et.al (2018). There are eleven column's six rows in a stack. There are five bricks in the sixth row, resulting 60 bricks in a stacking pan and there are six pans. Two workers take three different paths to pick the brick and put the brick in stacking pan.

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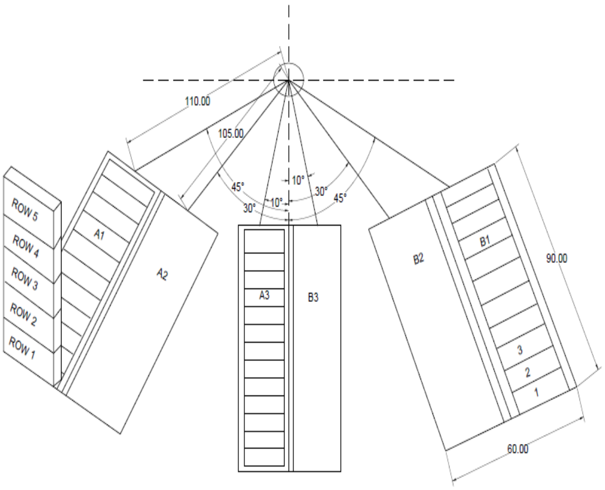
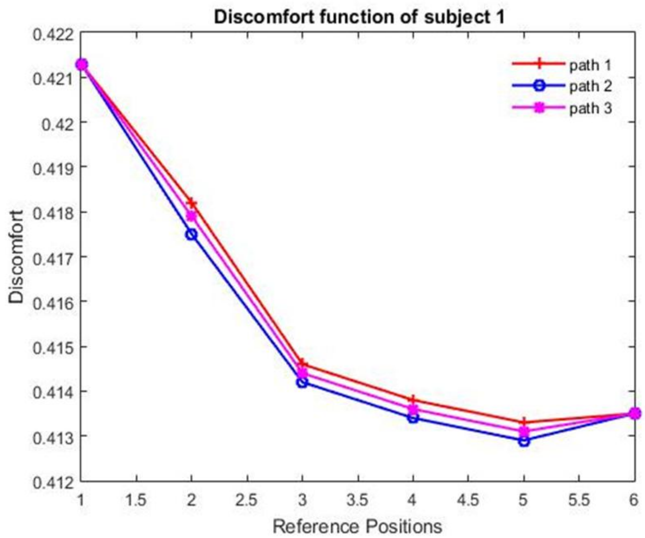


[Fig-4 Bricks stacking layout]

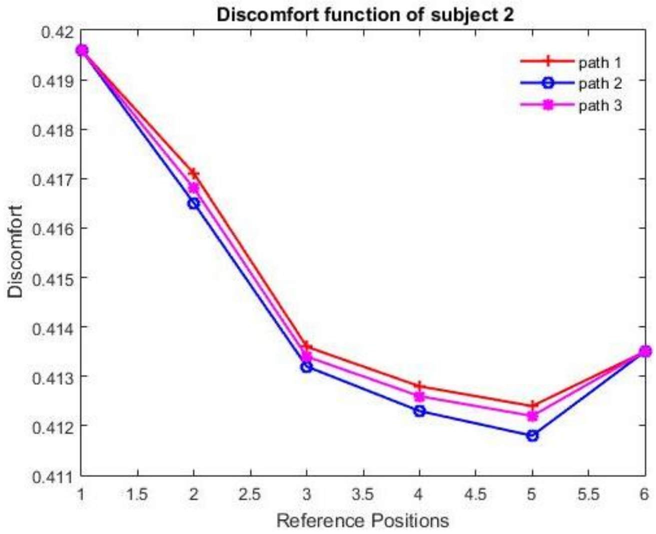
V. OUTCOMES AND DISCUSSION:

The yields of simulation are verified with respect to the objective cost functions i.e. discomfort factor and energy expenditure factor to the demanding arrangement of the workers in the present case. Once the brick is placed within uppermost range zone, a bend position of the body is necessary by a worker is a portion of workplace design. So, to ignore extreme trunk bending, lower positioned hip, knee and ankle also are to be bent to have desired bend position. For bend posture, bend in hip joint, knee joint and ankle joint is required to avoid the extra bend in the trunk joint.

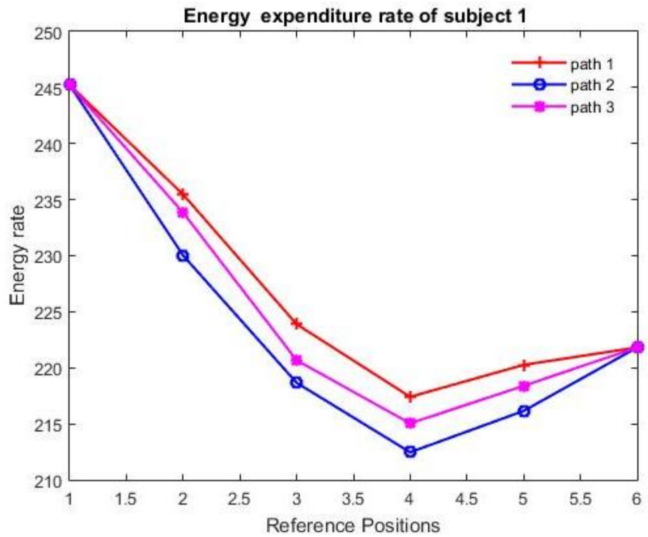


[Fig-5 Discomfort function of worker-1]

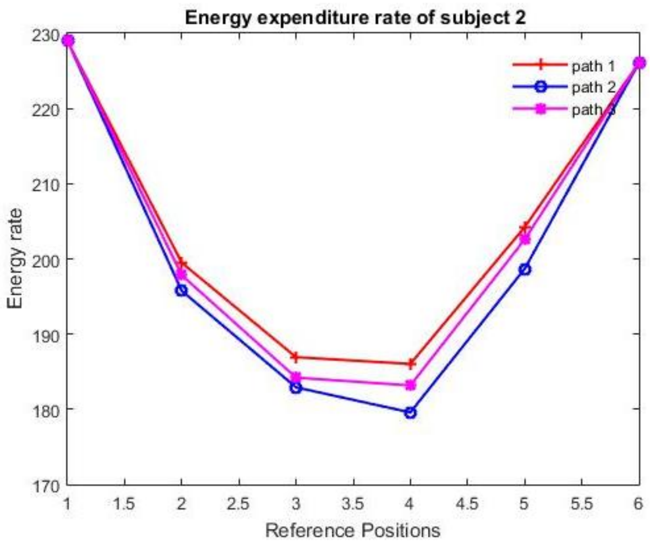
Figure-5 and figure-6 describes the discomfort factor for two workers in each three paths. For both the workers the path-2 is consuming less discomfort factor. Energy expenditure factors for both the workers for three different paths are shown in figure-7 and figure-8, and for both the subject less energy consumed in path-2. So, it is recommended to take path-2 for both the workers as it consumes less energy and discomfort rate is low.



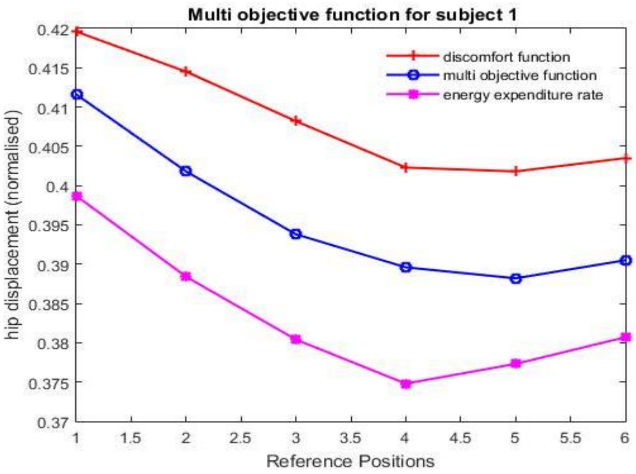
[Fig-6 Discomfort function of worker-2]



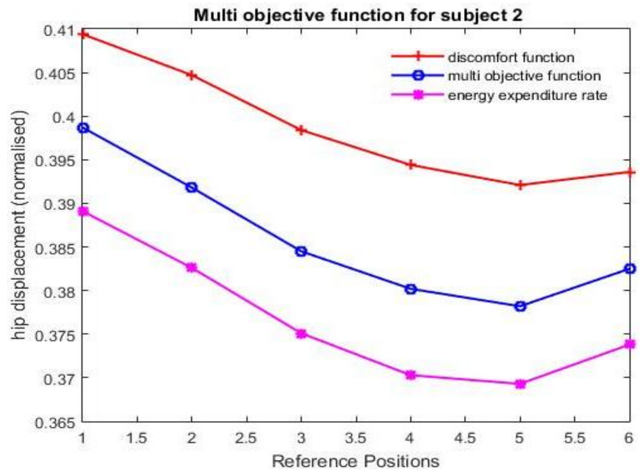
[Fig-7 Energy Expenditure for worker-1]



[Fig-8 Energy Expenditure for worker-2]



[Fig-9 Combination functions for worker-1]



[Fig-10 Combination functions for worker-2]

When we take multi objective function, discomfort factor and energy expenditure rate simultaneously for each worker as in figure-9 and figure-10. The graph plotted as hip movement in y-coordinate and reference point in x-coordinate. As obtained from graph the optimum posture having less energy requirement and a reduced amount of discomfort level is obtained by MOO technique. From the graphs it is obvious that there are a reduced amount of joint discomfort and a reduced amount of energy expenditure factor for worker-2. These three curves show that approving a tall worker for bend position to reduced quantity of the discomfort factor and energy consumption. From the above all discussion a reduced amount of joint discomfort function and a reduced amount of in energy expenditure rate shows the minimization of ergonomic risk factors.

VI. CONCLUSION

Thus, through earlier discussion, the worker's body parts motion during brick arrangement in fly ash bricks plant is monitored. The cause of sequence is explained and derivation of optimized parameters are done for body movement. For the posture prediction three methods are utilized they are discomfort method, energy method and MOO method. The results of above method are graphically illustrated and the results are analyzed and found to be MOO method giving better result. MOO method gives a compromise result between discomfort and energy method. It effected in improvement by reducing discomfort and energy to enhance the effectiveness of the objective function. Ultimately ergonomic risk factors are minimized.

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