

Effective Work Procedure design Using Discomfort and Effort Factor in Brick stacking operation- A case study

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Abstract— In this work a typical planning of movement of limbs and torso of the worker to be well design to reduce fatigue and energy of the worker. A simulation model is generated to suit the procedure and comply with the constraints in the workspace. It requires verifying the capability of human postures and movements in different working conditions for the evaluation of effectiveness of the new design. In this article a simple human performance measure is introduce that enable the mathematical model for evaluation of a cost function. The basic scheme is to evaluate the performance in the form of several cost factors using AI techniques. Here two main cost factors taken in to consideration are discomfort factor and effort factor in limb movements. Discomfort factor measures the level of discomfort from the most neutral position of a given limb to the position of the corresponding limb after movement and effort factor is a measure of the displacement of the corresponding limbs from the original position. The basic aim is to optimize the movement of the limbs with the above mentioned cost functions. The effectiveness of the procedure is tested with an example of working procedure of workers used for stacking of fly ash bricks in a local fly ash bricks manufacturing unit. The objective is to find out the optimised movement of the limbs to reduce discomfort level and effort required of workers. The effectiveness of the procedure in this case study illustrated with the obtained results.

keywords: ergonomics; human posture; optimisation; discomfort factor; effort factor.

1. Introduction:

Ergonomics normally deals with human and its behaviour in their work environment. In larger scope this examines the behavioural attitude of the human being while performing the job. Simultaneously it also considers the physiological limitations and capabilities of the human to achieve better performance in work place. In general the options are to modify either a new work environment which is to be designed an existing work environment is to be modified according to limitations and capabilities of both worker and work environment. These cases can only be decided after vigorous study on the limitations and capabilities of both worker and workspace. Also the works stress level should not exceed the limit which in turn causes health disorder and the safety of operator. So the objective of ergonomics is to provide healthy and safe productive workspace for the workers for the effective output.

Present human modelling and simulation in virtual environment is applied for ergonomic evaluation of interface between man and machine with help of computers and different available softwares, the



virtual environment and analysis is conducted. As the prototype design is in virtual environment it is not necessary always to create an actual prototype which in turn reduces the cost of production. Using digital mock-ups the proceedings of the operation can be virtually tested. The evaluation by changing the posture, position and level of work the procedure can also be evaluated. Ergonomist are not sure of operator's position and posture so they have to simulate a virtual man model in a particular workspace. Besides, these virtual human models have appeared as animated human prototypes that can be manipulated.

In this work an improvement of worker efficiency by planning effective movement of the limbs. The motivation is to find some performance measure to reduce the energy losses arise from the limb movement of the worker. Also the movement of limbs should be such that the discomfort of the worker in processing the work should be less as much as possible. For the purpose a simple human model is assumed for simulation in the work place. The objective is to evaluate the performance in the form of some factors dependent upon the limb movement and energy requirement for the limb movement.

2. Modelling of limbs:

For evaluating a simple model of a human is assumed as in figure 1. The straight lines are the representation of the limbs. These limbs are connected through joints as shown as filled circles. For representation simplicity the model shows only the arms, legs and torso part of a human.

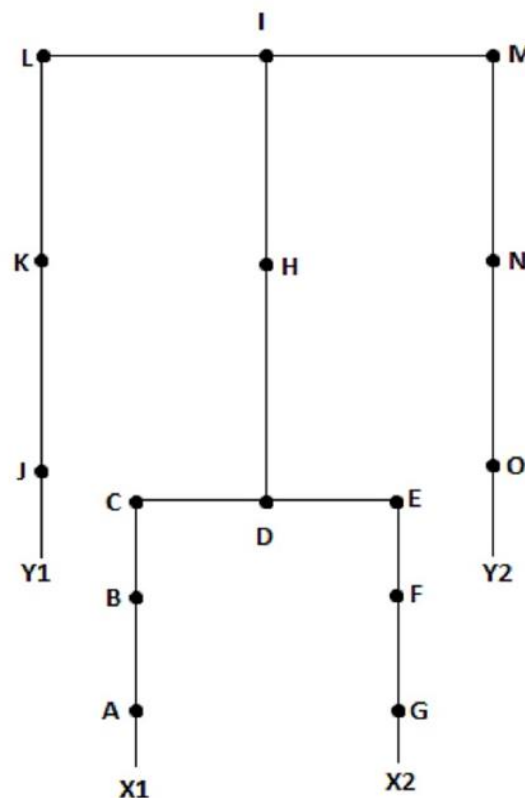


Fig 1: The Schematic Diagram of a human

Usually a person stands with his arms vertically hangs along the side of the torso. This is the most comfortable position and with minimum energy. Let this be named as most neutral position of the human. Any movement of any limbs changes the comfort and extra additional energy. In other

words the amount of discomfort and the effort required for the movement is the basis of evaluating the performance measure. Accordingly two factors, discomfort factor and effort factor, is used.

In figure-1 the schematic diagram of modelled human body consists of 15 joints. Out of this 3 joints are assumed to have revolute motion in two perpendicular directions and other 12 joints only have single revolute joints. Hence the model is of 18 DOF. These 18 DOF model is represented by q_i ($i = A, B, C, \dots, O$). Each q_i has a upper limit (q_i^U) and lower limit(q_i^L) i.e. the q_i value is constrained in between q_i^U and q_i^L . The discomfort function is measured as the difference between the centre of gravity of the limb at a particular position w.r.t. the neutral position. This can be expressed as $q_i - q_i^N$. Usually the amount of discomfort varies according to corresponding joint capabilities. Each joint is specified with a weight function the total discomfort of all joints can be expressed as

$$f_{discomf}(q) = \sum_{i=1}^n w_i |q_i - q_i^N| \quad (1)$$

The weight functions W_{id} 's are so selected such that the joints having more discomfort have more weightage compare to joints having less discomfort. Similarly another function is moved which gives the decision according to the displacement of the links from the neutral position. The change in the initial position to the position under consideration gives rise to the effort function which is related to displace.

For movement of limbs from one initial configuration q^{int} to the final configuration q^{fin} and represented as

$$f_{effort}(q) = \sum_{i=1}^n w_i |q_i - q_i^{int}| \quad (2)$$

Note that joint limits depend on the initial configuration of each joint.

3. Denavit-Hartenberg representation of the model:

In robotics a standard procedure is used to express the joint and links for finding the position and orientation of the robotic arm. This was proposed by Denavit and Hartenberg in 1955 and well accepted in robotic field. This represents all the links through the intermediate joints through a systematic representation. The algorithm used for so is known as DH representation. This algorithm uses two link parameter i.e. θ_i and d_i and two joint parameter a_i and α_i . The DH parameters for the model in fig.1 is described in table 1

For an n -DOF model, the required point position vector can be expressed in terms of joint variable as:

$$X = x(q) \quad (3)$$

Where $q \in \mathbf{R}^n$ is a generalised n degree coordinate system and $x(q)$ is a combined matrix arises from successive multiplication of transform matrices depending upon n - DOF as:

$${}^0T_n = {}^0T_1 {}^1T_2 \dots {}^{n-1}T_n = \begin{bmatrix} {}^0R_n(q) & x(q) \\ 0 & 1 \end{bmatrix} \quad (4)$$

Where, $x(q)$ is the vector of displacement and iR_j is the corresponding rotation matrix for i and j . This matrix iR_j has 4X4 homogenous transform matrix between two links i & j which is first established. Then by systematically according to the links this is multiplied to get the final coordinates of the point interest.

D-H Parameters				
JOINTS	θ_i	d_i	α_i	a_i
A	q_A	0	0	L_A
B	q_B	0	0	L_B
C	q_C	0	$-\pi$	L_C
D ₁	$\pi/2 + q_{D1}$	0	$\pi/2$	0
D ₂	$\pi/2 + q_{D2}$	0	$\pi/2$	0
E	q_E	0	$-\pi$	L_E
F	q_F	0	0	L_F
G	q_A	0	0	L_G
H	q_H	0	0	L_H
I	q_I	0	0	L_I
J	$-\pi/2 + q_J$	L_J	$-\pi/2$	0
K	q_K	0	$-\pi/2$	L_K
L ₁	$\pi/2$	q_{L1}	$\pi/2$	0
L ₂	q_{L2}	0	$-\pi/2$	0
M ₁	$-\pi/2 + q_{M1}$	L_{M1}	$-\pi/2$	0
M ₂	q_{L2}	0	$-\pi/2$	0
N	q_N	0	$-\pi/2$	L_N
0	$\pi/2$	q_O	$\pi/2$	0

[TABLE-1]

4. Optimisation formulation:

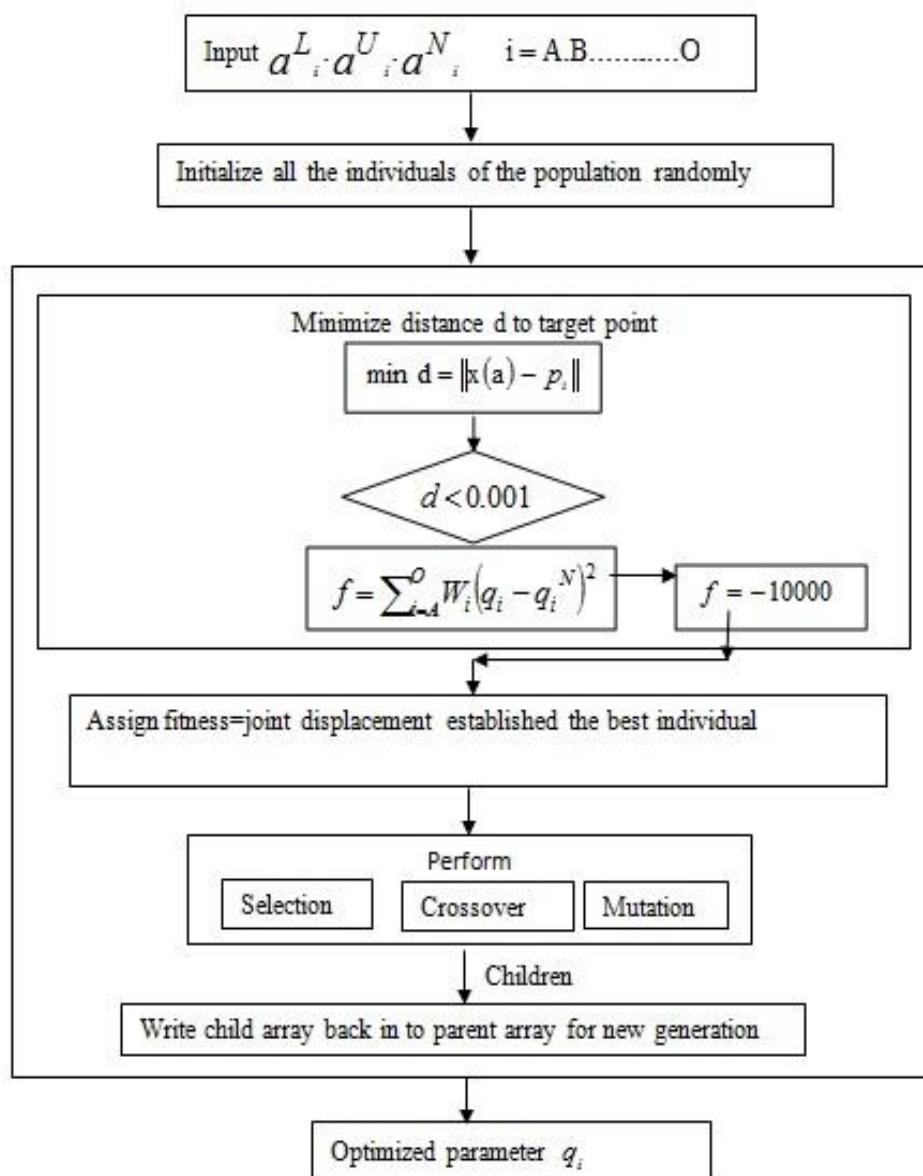
The objective of this work is to obtain minimum energy required for the efficient operation of the job. This is evaluated by comparing between the different possible solution options. Genetic algorithm method is an AI method which finds near optimum solution out of a number of random generated solutions.

The job is carried by moving the limbs through a number of steps with some desired destination position and the hand finally reached the required position and orientation. Between the starting position of joints and destination position of the joints, a number of intermediate points of the hand are located. To achieve the configuration of all the joints such that the path of hand should pass through the located position with minimum discomfort and effort is the goal of this study.

The human model presented in this work is consisted of 18 DOF, each DOF is varies from lower limit to upper limit as per the capabilities of human being under consideration. So considering small steps in each DOF a large number of position sequences can be randomly generated. This random generation of the location of the particular joint may give a quick result satisfying the objective cost functions. But as the number of data point generation is vary huge and the system is incapable of handling such a large database which consists of all possible combination of joint locations. In order to reduce this

taking a limited number of sample solution satisfying the objective cost function will generated by randomly selecting the joint locations.

So GA is one of the optimisation algorithms which modify a solution space satisfying the objective cost function by modification of points on the solution space locally. Different weight age can be achieved in changing the position of each joints according to difficulty achieved in changing the position of each joint which drives the solution accordingly to the desired conditions and smoothly improves the fitness function to generate better result.



[Fig-2 Flowchart of optimisation]

In each temporal increment (called generation) parents are selected to breed fertile offspring. This operator emulates the Darwinian principle of natural selection, basing solely on the fitness value of the

individuals. In the problem domain the objective function characterizes the performances of the individuals (phenotypic manifestation of genotype). A mapping function is needed to transform the objective value to a nonnegative fitness value for the use of selection mechanism that determines which individuals will breed. This process is called selection.

Alteration makes changes in hereditary endowment of the breeding population through successive generations causing evolution.

The fitness function is derived for this problem as

$$f = \frac{1}{f_{effort}} + \frac{1}{f_{discomf}} \quad (5)$$

Using this fitness function GA calculates the solutions.

The GA is used to calculate the position of all joints for different location points of hand and optimised to get minimise discomfort and effort. The flowchart of the procedure carried out is described in fig.2.

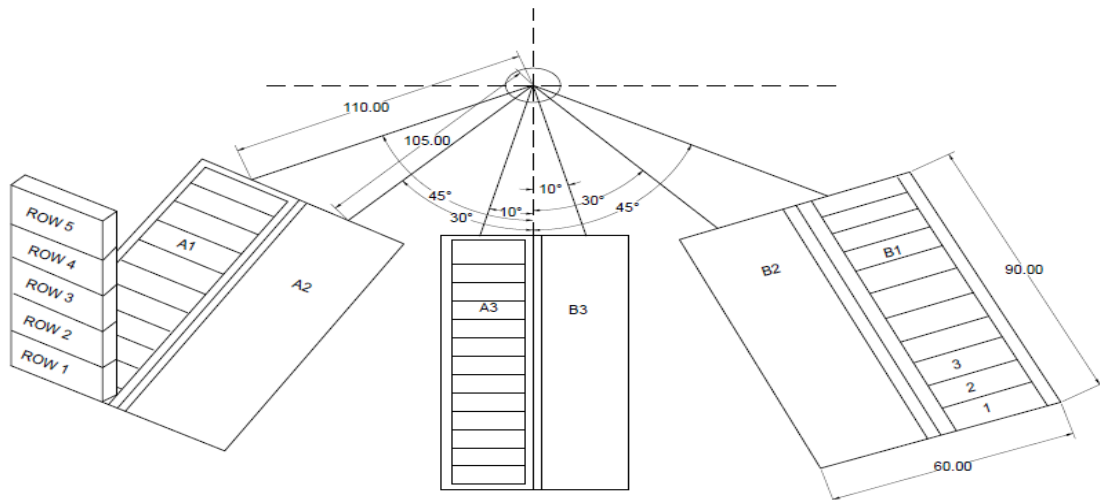
For this case study within the upper and lower limit of each DOF a position of joints are randomly generated. After trial and error it is found that a 60 population is giving a good result. Hence the population size is started with 60. By crossover procedure another 60 off springs has been generated to make the solution pull to 120. Randomly this 60 off springs some mutation operation is given in the order of 1% is given. Then 60 out of 120 has been selected according to fitness function. Best 60 is selected for the next generation and rest 60 is rejected. This process continued till there is till there is a convergence i.e. there is not much variation in the average population fitness is selected.

5. Case study:

The method discussed earlier is utilised to find the discomfort and effort function for a worker for specific job. To verify the model and its effectiveness, a worker in a fly ash bricks manufacturing unit is considered as a case study. In these experiment two workers one is moving clockwise direction and the other one is moving anti clockwise direction for picking the brick and place that in the stack. At a time these two workers are putting the bricks in six stacks. Several videos are captured from which different motions are captured. These motions are analysed for obtaining different posture and its corresponding position of each joint which is utilised for ergonomic analysis.

The stacking operation is carried out by two workers having. These two workers stack 360 bricks of size 22.86 x 7.62 x 12.7 mm and weight 6.5 kg in three trays of size 90 x 60 x 15.24 cm. The schematic diagram of the brick stacking layout is illustrated in fig-3.

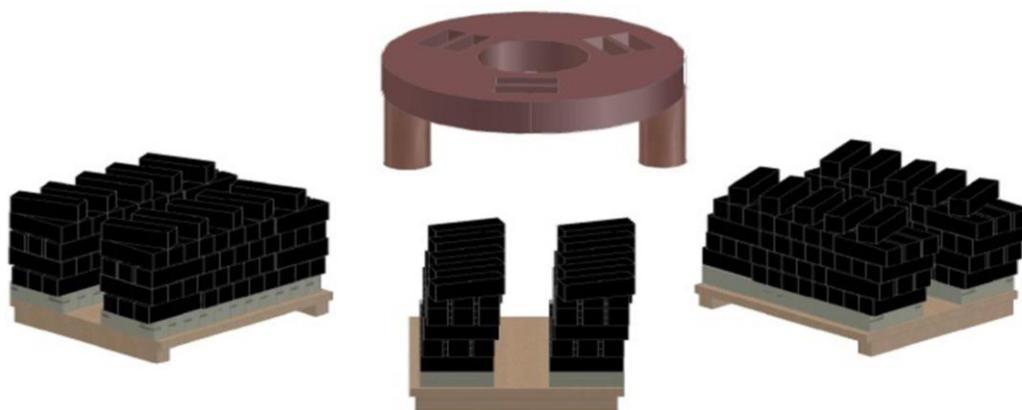
Here we consider one worker for our study having height 162.5 cm and weight 75 kg. The worker put the bricks in stack A1, A2 and A3 stack. Each stacking pan contains two stacks.



[Fig-3 SCHEMATIC DIAGRAM OF BRICKS STACKING LAYOUT]

Each stack contains 60 bricks in six rows. In first five rows, each row contains eleven bricks and the sixth row contains five bricks. The worker is putting continuously bricks in the stack. Several videos are captured while stacking operation is carried out for two workers out of which one is considered for ergonomic analysis. The two main cost functions “effort function” and “discomfort function” is considered for analysis.

The stacking operation showing each stack with bricks is showing in figure-4.

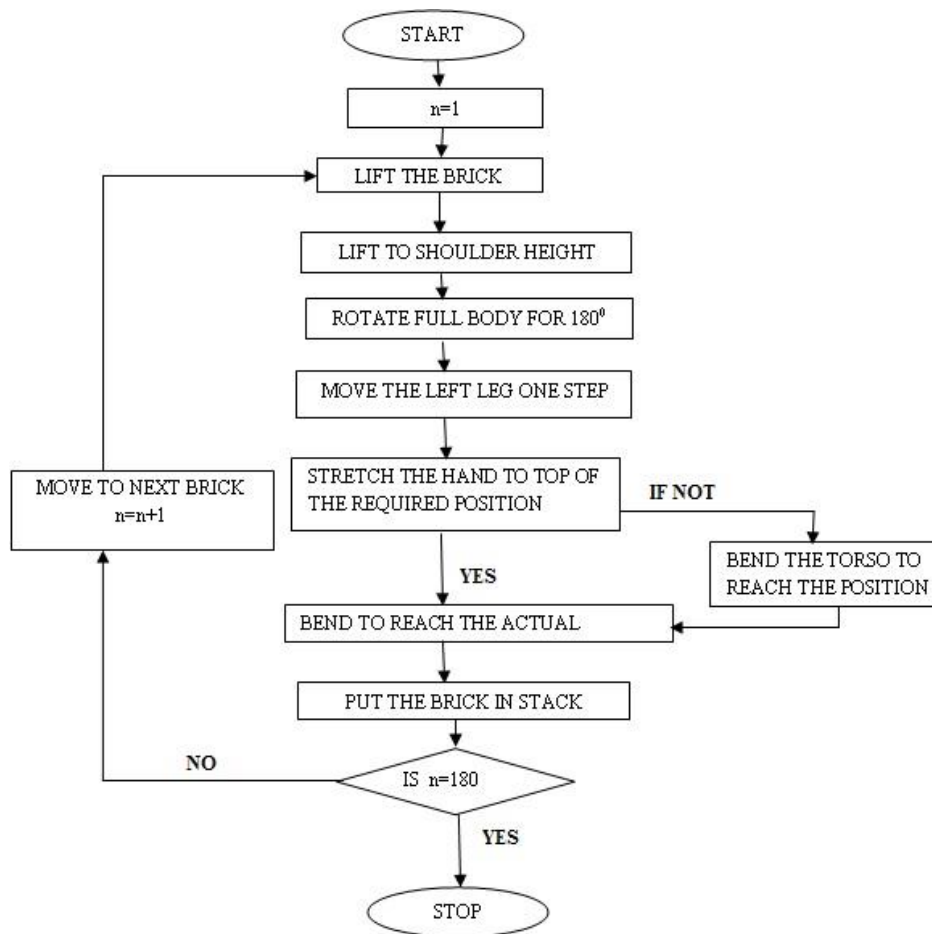


[Fig-4 Fly ash brick stacking]

6. Steps followed by worker:

In order to observe the nature of work of the worker under consideration the image for a number of cycles is video graphed. The video graph is thoroughly observed for a number of times and this gives rise to the steps of procedure of stacking as follows.

- Total time available to stack one brick is 5.5 seconds (production rate).
- The worker holds the brick at a height 106.68 cm.
- Take a turn of an angle of 180°
- Move the left leg one step and bend to the stacking height.
- Put the bricks in stack



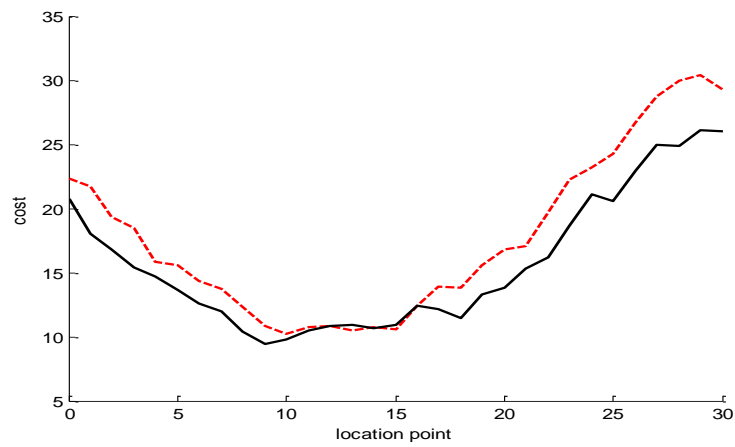
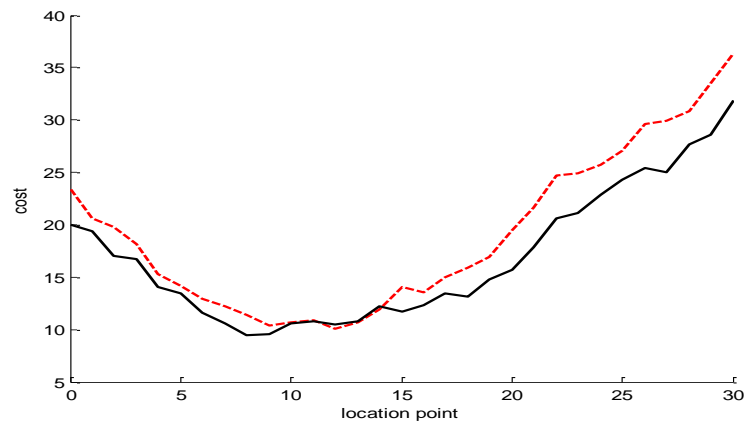
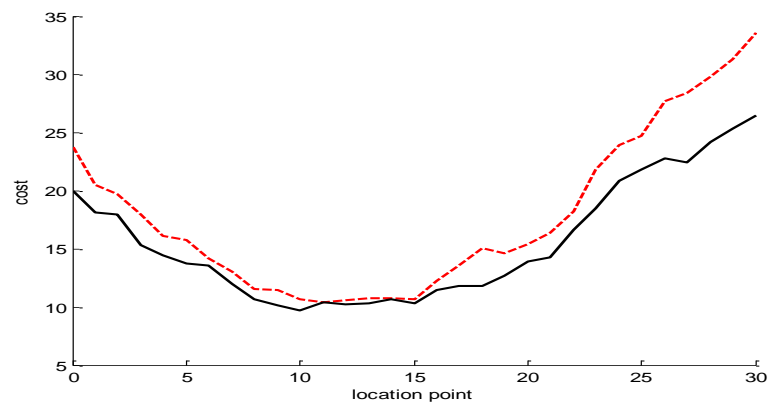
[Fig-5 Flowchart of steps followed by worker]

The above steps are the basis steps used for analysis and simulation of the movement of different body parts. Flowchart of steps followed by worker is given in fig.5.

The output of simulation is checked for the two objective functions i.e. effort function and discomfort function to the particular configuration of the worker in the case study.

In this work out of 60 bricks in one stack the movement from mould to stack for three bricks is presented. In the following three figures the output of the procedure is shown.

The movement of hand is moved towards 30 numbers of intermediate points. These points are located from the video of the worker.

[Fig.6 (a) Bricks stacking of 5th Row][Fig.6 (b) Bricks stacking of 3rd Row][Fig.6 (c) Bricks stacking of 1st Row]

Keeping this location points the cost function for the movement of this video is obtained is calculated and shown in fig.6 as dotted lines. The cost function calculates by this procedure is shown as solid lines. The figure above it is observed that the cost function obtained is less to proposed method of evaluation hence it is effective.

7. Conclusion:

By the above simulation model the motion of the body parts of the worker in brick stacking operation in fly ash bricks is considered. Steps for the purpose are explained and optimized parameters have been derived. AI technique i.e. GA is used to optimize the positions. Result is shown in graphs and it shows the effectiveness of improvement in the objective cost functions i.e. effort function and discomfort functions is improved. This will be extended in future work for more degrees of freedom and for prismatic joints. Also simulation of full body motion for stacking will be conducted. Further it will be extended to other work places.

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