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Merikh Nejadasl, Atieh; El Makrini, Ilias; Van de Perre, Greet; Verstraten, Tom; Vanderborght, Bram

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Graphical Abstract

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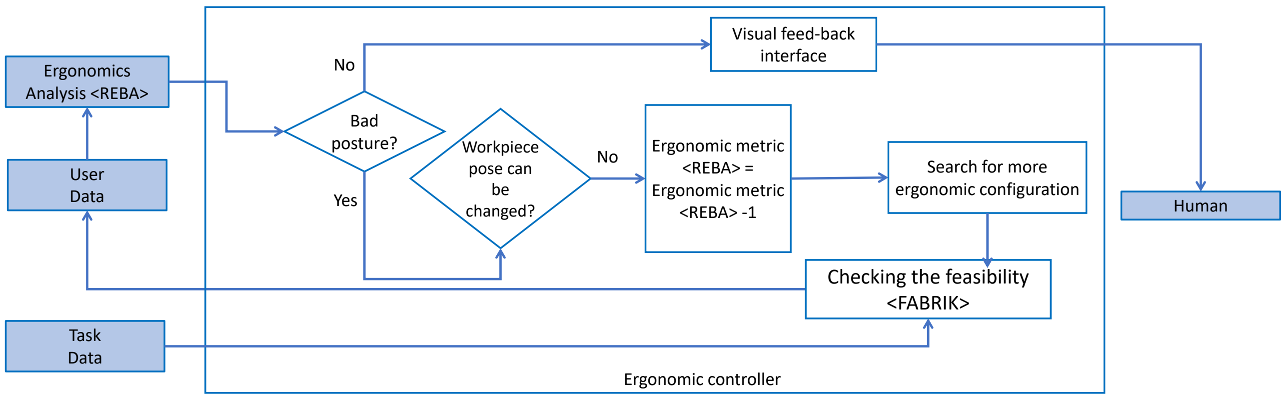

Highlights

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- The postural optimization algorithm can show the correct way of doing a task for industrial workers.
- The worker ergonomic condition is assessed via motion capture devices, and in case of a risk, the optimization algorithm offers them a more ergonomic posture.
- The validity of the algorithm tested on a dataset consisting of different people with different body morphologies.
- We present an algorithm that can be used in the control loop of exoskeletons or collaborative robots to integrate ergonomics constraints into the worker's routine.

A Generic algorithm for computing optimal ergonomic postures during working in an industrial environment

Atieh Merikh-Nejadasl[a,*] (Researcher), Ilias El Makrini[a], Greet Van De Perre[a], Tom Verstraten[a] and Bram Vanderborght[a]

[a]*Robotics and Multibody Mechanics Research Group, Vrije Universiteit Brussel and Flanders Make, Belgium, www.brubotics.eu*

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ABSTRACT

The present study tries to decrease the risk of work-related musculoskeletal disorders for industry workers by proposing a generic algorithm that recommends an optimal ergonomic posture for accomplishing tasks in an industrial environment. In the case of a dangerous ergonomic pose, the optimization algorithm starts by heuristically changing it to a more ergonomic one. Each recommended posture's feasibility is tested with an inverse kinematic method that can predict the worker's behavior for accomplishing a task. This iterative optimization procedure continues until the optimal ergonomic pose for the worker is achieved. The algorithm's validity is tested in thirteen cases, people with different gender (50 percent male, 50 percent female) aged between 20 and 35, and different height and body morphologies. According to studies, there is a connection between musculoskeletal disorders and the wrong posture for accomplishing tasks in industries. We suggest an optimization algorithm that can indicate the worker the optimal ergonomic pose by considering task constraints in real-time.

1. Introduction

Work-related musculoskeletal disorders (WMSD) are the single largest category of work-related injuries and responsible for 30 percent of all workers' compensation costs [6]. These injuries lead to a yearly cost of 240 billion euros, which is the effect of MSDs on European workers [6]. Between all the elements that result in WMSDs, repetitive movements in a not suitable posture can cause several injuries in the industrial environment [24], because it can cause excessive loads to the human joints. Some papers investigated the aggregated effect of activities on the joints and addressed this issue by modeling these effects [25]. A convenient way of reducing WMSDs in industries is to integrate ergonomics concerns into the planning activities [20], i.e., improving the worker's physical health condition while maintaining the productivity of the companies. With the help of collaborative robots (cobots) or exoskeletons, the workers can work in a more ergonomic state in industries. During the collaboration with cobots in industry, the hard and physically tough tasks are done by cobots [13]. Alternatively, in some cases, exoskeletons are the solution to support the workers for hard tasks in the industry [28]. Assessing the ergonomic condition of workers in the industry is done in some papers to develop an algorithm to design an optimal co-manipulation between cobot and huaman [26]. Usability and acceptance of exoskeletons and cobots in workers' routine investigated by other papers [14, 12].

The prerequisite of the ergonomic health integration in planning is to have a tracking system that can monitor the worker's body in the workspace while accomplishing a task and alert for reducing the static joint overloading [23]. In some risk assessment methods, some worksheet can be filled out, based on the simulated kinematics of the human operators acting in the environment [35]. Alternatively, a practical manual assesses employee conformity with European Union legislation covering the safety and protection of workers' health [10]. In some cases, the workplace analysis is done by commercial software that sets off-line and uses biomechanical approximations to calculate possible values of the muscle activation, reaction forces, and joint moments based on human performance characteristics gathered statically [33].

The observational methods that are done manually may be time-consuming and have limited accuracy. The process of human tracking can be automatized by the development of human tracking technologies such as depth cameras [40]. The automatized version of these observational methods was investigated and used by many papers [11]. Centralized methods for real-time identification and kinematic tracking developed to show the musculoskeletal model of human arms [15]. These devices would estimate potential musculoskeletal risks without interfering with workers' typical movements at the workplace. They are providing direct feedback to the end-user who would be continuously monitored directly at work. Some papers work on this feedback system that can give feedback about human behavior in real-time. Furthermore, give information about muscle activities and the intended configuration for a task [32]. These feedback data can be used for the ergonomic improvement intent. In this way, the workers would alert in case of any wrong posture and modify it [1]. The posture modification needs to be done systematically and based on some instructions. To be able to recommend an optimized posture for accomplishing any task in the industrial environment. First, we need to predict human behavior to be able to optimize it.

When the industry worker accomplishes a task, he/she may use some customized movements to reach a workpiece. Goal-directed movements, such as moving the body to reach

*Corresponding author.
E-mail address: atieh.merikh.nejadasl@vub.be (A. Merikh-Nejadasl)
ORCID(s): 0000-0001-6703-5046 (A. Merikh-Nejadasl)

a target, can be predicted by inverse kinematics to predict reaching a posture [21]. It solves the set of joints' angles from the end-effector's location and orientation. However, because the number of degrees of freedom (DOF) of the human body is generally higher than the number of equations imposed by the task, there exists more than one possible solution for completing a task [41]. However, not all of them are viable for accomplishing the task according to ergonomics concerns. Finding an inverse kinematic solution is possible by describing some constraints for the solution. For example, In some methods, a solution is founded that optimizes the time, energy, and torque while reaching a target [19]. Alternatively, in some cases, comfort level is used as a constraint for the optimization algorithm [42]. Some papers defines a cost function that optimizes the worker's body posture according to their concerns for the best ergonomic human configuration [7, 8, 37]

What is missing in this regard is using a fast and reliable method that monitors the whole worker's body, makes workers aware of the wrong positioning of joints, and finally proposes the best possible stance. This research aims to offer a novel method to automatically monitor, assess, and optimize the workers' posture during industry tasks. Many methods evaluate the risk of musculoskeletal disorders. Here we used the REBA [18] method. The REBA method demonstrated convincing in assessing overall risk, classifying most of the workstations as high risk compared to other methods [9]. Moreover, choosing REBA in this stage is that it can give a quantitative measure for the ergonomic state of the worker's posture. The possibility of achieving the job under the constraints is investigated by the algorithm presented in this paper. The presented approach is based on a fast and reliable forward and backward reaching inverse kinematic algorithm (FABRIK) [3]. The current optimization algorithm developed to optimize user posture under task constraints. Finally, this optimized possible posture is introduced to the employee by a user feedback interface.

The rest of this paper is organized as follows. In section 2, the problem is described. In section 3, there is an overview of the optimal posture algorithm. Section 3.1 describes the ergonomic assessment method that computes the ergonomic status of each posture based on its kinematic data. Section 3.2 describes the procedure for finding the optimized posture. Section 3.3 describes the FABRIK inverse kinematic approach and its role in the optimization algorithm. Section 4 describes the implementation results and validation process and finally Section 5 discusses the result.

2. Problem Statement

To reduce the risk of MSDs and improve ergonomics, an ergonomic assessment method evaluates body posture. The worker might face a nonergonomic situation in the workplace that makes him/her use a dangerous posture to accomplish a task. For instance, consider a worker who needs to lean forward multiple times to pick an object for assembling a workpiece. Too much forward-leaning during the work is a repetitive task that puts the worker's body in a nonergonomic situation numerous times. In such cases, the first step is to investigate the possibility of adapting the workpiece position. If the manipulation of a workpiece pose is not possible, we solve the optimization problem 1 to propose the most optimized posture to the user to accomplish the task. The formal definition of the specified problem comes in the following:

$$\min_{\text{Input data}} f(g(\text{Input data})) \text{ s.t. } \textit{task constraints} \qquad (1)$$

In the above equation, g is a function that maps input data (kinematics and dynamics data) to enter the ergonomic analysis function, f. In this definition, g is a general function that enters any input data and is ready for ergonomic analysis. The problem is to minimize the $f(g(Input)))$ subject to task constraints. The optimization algorithm is generic because its functionality is not dependent on the f and g functions, and the proposed method is general. These libraries' independence and modularity make it possible to change one and not influence the other ones.

In the present study, we developed the FABRIK module in place of g, which only inputs kinematic data (joints pose) and the REBA method in place of f. Still, the optimization algorithm's generality and modularity make it possible to replace the g function with other methods like Kinematics and Dynamics Library (KDL) [30] or any other method that considers all dynamics forces and kinematics data. The latter is considered as the future work of this paper. Moreover, the current ergonomic analysis function, REBA, can be replaced with any other ergonomic assessment methods like RULA or any other ergonomic assessment methods to give a quantitative metric about the user's ergonomic condition. Finally, the reason for choosing FABRIK and REBA in this paper has been described in its relevant sections.

3. Methodology

The Methodology starts by proposing a framework that can suggest the worker's most optimized posture while he/she is doing a job. The schematic of this framework is depicted in Figure 1. First, the user kinematics data (joints' position, joints' orientation, and joints' constraints) are ergonomically assessed by an ergonomics analysis metric, which gives a quantitative measure about the ergonomic condition of the user. The ergonomic assessment metric (REBA in this case), and task constraints like the target's position and orientation, which the user should work on, are taken as the ergonomic controller's input.

The algorithm continues by reducing the total REBA value by one unit and takes this new REBA value as an input for the optimization module that results in new user data. In this stage, the algorithm's loop finishes, and it continues until the good posture achieves and be shown in the visual user interface to humans. The visual user interface details are out of this article's scope, but the general idea is to show the optimized posture after completing the optimization algorithm. The general plan is to track the user's change in posture. If the position changes, the algorithm should start

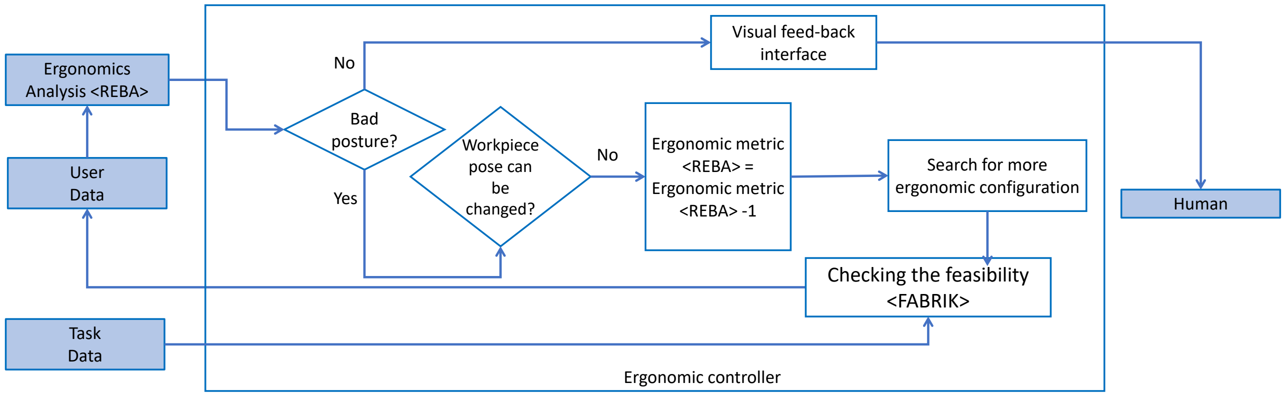

Figure 1: Ergonomics controller scheme. It describes the algorithm procedure in case of not changing the workpiece location. The steps are needed to be done to recommend the most optimized posture for accomplishing a task.

to evaluate the posture, do the optimization, and announces the optimization in a visual feedback system.

The details of the optimization module are further described in the following sections. The optimization module first searches for the joints configuration that can support this reduction. Search and find the optimal joints constraints methodology described in section 3.2. In each step, REBA reduction is made by considering two criteria. The possibility of the new shape and the ease of achieving this new posture. Quickly achieving a new posture means it has the minimum distance from the current body posture, and worker can easily change his/her current stance to the new one. Fulfilling these two criteria, REBA reduction followed by two steps. First, finding the suitable joints' constraints second evaluating the possibility of achieving this configuration by an inverse kinematic method (FABRIK [3] in this case). FABRIK is an inverse kinematic approach for computing natural human movements in realtime. The task data means the pose and constraints of the task that will restrict the inverse kinematic solution, and the final configuration, which is selected, should fulfill the task constraints. The role of FABRIK in the algorithm is described in section 3.3.

3.1. Ergonomic Assessment Method

Many ergonomic assessment methods can evaluate the risks of musculoskeletal disorders. Some of the known methodologies for ergonomic assessment are the National Institute for Occupational Safety and Health (NIOSH) that assesses the manual material handling risks associated with lifting and lowering tasks in the workplace [34], the Occupational Repetitive Action (OCRA) for ergonomic assessment of repetitive tasks [10]. The Rapid Upper Limb Assessment (RULA), Rapid Entire body assessment (REBA) methods [27, 18] that assess postures during static or rapidly changing actions. The values are incorporated into a final evaluation of the given posture, ranging from 1 (comfortable position) to upper value (unacceptable stance, calling for immediate action). In this paper, we use the latter method, REBA, to give a quantitative, quick, and short explanation of the posture's overall ergonomic status. It has the capability of being automated. By incorporating the RGB-D cameras and, in this case, the Microsoft Kinect sensor [22], we can continuously monitor the joints' position and orientation. These data are updated by any change in the user's posture and are used for ergonomic assessment. The REBA can give a brief explanation about the ergonomic status of the user by knowing the posture joints position and orientation in real-time [36] that is captured from the Kinect sensor. Several papers also benefited from the automatic procedure of REBA for task allocation between workers and collaborative robots in the industry in case of a non-ergonomic situation for the workers [13]. The ergonomic assessment method is used for this algorithm is entirely modular. It provides the user with the ability to replace it with any other technique to give quantitative feedback about the ergonomic condition to include more data for ergonomic evaluation. In the REBA calculation procedure, the human skeleton is divided into two groups, neck, trunk, leg in the first group. The upper arm, lower arm, and wrist are in the second group. A value is determined based on its angle about its neutral pose for every part in each group. Finally, these values incorporate the given posture's final evaluation with the tables' help, ranging from 1 (most comfortable posture) to 12 (most dangerous and unacceptable posture). The ergonomics assessment of a posture in dynamic form needs further data that several papers addressed [17, 38]. However, as this paper intends to investigate the optimization algorithm, we are satisfied with the REBA technique. Any more ergonomic assessment data or a replacement with the technique can adapt to this framework. The final REBA score can be interpreted as a measure to start the optimization algorithm. It is higher than a threshold that shows the necessity of a change and initiation of the optimization algorithm to prevent further damages.

3.2. Finding optimal Posture

As stated before, finding the best possible posture is a stepwise procedure in this present proposed algorithm. In each step, as depicted in Figure 2, the total REBA score reduces by one. The lower the REBA score, means more ergonomic posture. As we reduce the REBA score, one count, we face multiple body configurations that all correspond to this new REBA score. Selecting one of these configurations and proposing it as the selected configuration for the continuation of the algorithm is this section's subject. In the following, the procedure for selecting one of these configurations is described. Then in the next section, we investigate the feasibility of the selected configuration by inverse kinematic method (FABRIK).

Search for optimized posture: To optimize the worker's current posture, we reduce the REBA score by one unit. As stated before, computing the REBA score is done in 13 steps. In this method, the whole human split into two main groups. Neck, trunk, legs stay in the first and upper arm, lower arm, and wrist in the second group. In each step, based on each body part joint angles, a specific score is given to that part. Finally, by using tables, each step's score results in the final total REBA score that specifies the entire body's ergonomic status. Figure 2 shows that for an arbitrary total REBA score of 5, there is an array of 6 values that each cell contains the REBA score of that body part. If we have each joint angle, determining the REBA score is a unique procedure that is just stated according to the REBA computation procedure. However, if the reverse procedure is decided, it may result in many possibilities. These multiple possibilities happen because there is more than one combination of segment's score, i.e., joint angles exist, resulting in equal REBA value. As depicted in Figure 2, the REBA score of 5 is reduced by one unit to a new REBA value of 4. In this reduction, we face lots of combinations that all result in a REBA value of 4. For example, according to REBA tables, the two score combination of [1,2,2,3,1,3] and [2,1,2,3,1,3] that each number is the score for neck, trunk, legs, upper-arm, lower arm, wrist respectively will result in a total REBA score of 4. Moreover, this difference in segments' score results in different joint angles. To continue the algorithm procedure, we should decide between these multiple possibilities and pick the best combination that reduces REBA value and moves the current posture to this new proposed body configuration.

Picking one of these possibilities is the matter of discussion of this part. What is apparent is that all of these possibilities can lead us to the new reduced REBA value that we intend in the algorithm, but the worker's current posture can restrict our choices. The current REBA value of the operator has information about the operator's joints angle. To change this current posture to a more ergonomic one that needs to be done to spend minimum energy and most naturally. One way to achieve that is to pick one possibility with the minimum distance with the current scores, and the minimum joints' angle will be changed during this transformation. To find the nearest array to the array which defines the current posture, we calculate the pairwise distance between these two arrays. Finally, the score set, which has the minimum distance to the current one, is announced as the next configuration that leads the human to REBA score reduction in the most natural way. The next step is to map each REBA score combination to its correspondence joint limitation. Each score set determines the range of joints motion; for example, if the neck score is one, it means that the neck joint angle should be between 0 to 20 degrees. The complete procedure is shown in the algorithm 1 pseudo-code. In each step of the optimization algorithm, the REBA score (`reba` variable in the algorithm) decreases by one unit, all the REBA arrays that correspond to this reduced REBA score are found and sorted based on their distance to the current posture and are saved in the `rebaArrays` variable. Then we should see that each element of `rebaArrays` is feasible or not. For checking the feasibility of each element of `rebaArrays` first, we use the `JointLimits` function that map each `rebaArrays` element to `theta`. `theta` saves each joints' limits, then these limits beside target position, current joint's pose, twist limitation for each link, and solution tolerance are fed to the `FABRIK` function for checking the feasibility. If the FABRIK cannot find any solution based on these constraints up to the end of the loop, i.e., for all iterations `solFound == False`, the algorithm terminates. Moreover, the final joints configuration announces as the most ergonomic posture via the visual feedback interface.

Algorithm 1: Finding optimal posture algorithm (whole human body)

Input: Target position and orientation: T, initial joint's position and orientation: P_{init}, joints' limits: θ_{init}, twist limitation for each bone: $\mathcal{T}$, solution tolerance: $\mathcal{E}$;

Result: Final joints' position and orientation: `p` and `reba`

```
p[][] ← P_init;
theta[][] ← θ_init;
reba ← Compute REBA of initial joints' pose;
rebaInitArray[] ← REBA array of p;
while reba >= 1 do
    // Reduce total REBA score by one unit
    reba ← reba-1;
    rebaArrays[][] ← Find all REBA arrays that
      correspond to reba score;
    rebaArrays ← Sort all arrays of rebaArrays
      based on their distance to rebaInitArray;
    // find the number of arrays in rebaArrays
    n ← rebaArrays.length();
    counter = 0;
    solFound ← False;
    while !solFound && counter < n do
        theta ← JointLimits(rebaArrays[counter]);
        [p , solFound] = FABRIK(T,p,theta,𝒯,ℰ);
        counter++;
// Report the last joint configuration (position
   and orientation) via user interface
return (p,reba);
```

If `solFound` becomes true, it means the FABRIK could reduce the REBA one step successfully. The algorithm contin-

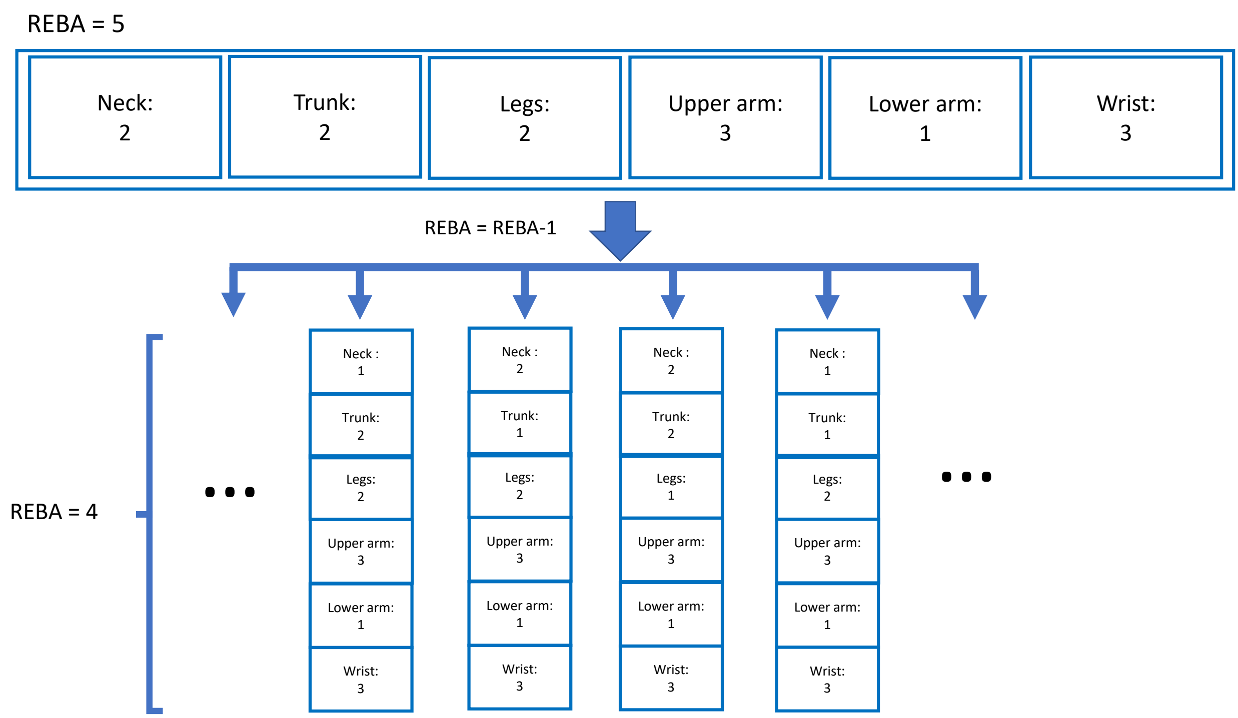

Figure 2: Multiple choices exist to reduce the REBA score from an arbitrary value of 5 to a new reduced value of 4. There is more than one possibility that can satisfy this intent.

ues for more REBA reduction, but if `solFound` never becomes true for none of the sorted `rebaAarrays`, the algorithm terminates. This final REBA and its corresponding joint positions and orientations are announced as the optimized REBA and configuration, respectively. The complete description of this process is described in 3.3.

3.3. Feasibility of optimized posture:

After finding the closest configuration of joints constraints that can lead us to the REBA reduction, we should investigate each configuration's feasibility to investigate the possibility of task completion under these new constraints. First, the possibilities that are found earlier are sorted based on their reachability to the current posture. The inverse kinematic method, FABRIK, solves the posture by applying the updated joints limitation derived from the selected possibility. As soon as the inverse kinematic method can find a solution, the loop is completed, and the algorithm restarts by reducing the REBA value one more unit. However, suppose the FABRIK could not find any solution by testing all the possibilities. In that case, we conclude that the REBA reduction is not possible for these task constraints, and the last REBA score is announced as the most optimized posture. In this part, we first describe the FABRIK, then its role in the algorithm is described in the following.

3.3.1. Forward and backward reaching Inverse kinematic (FABRIK)

This paper used the Forward And Backward Reaching Inverse Kinematics (FABRIK) method for our human chain simulation. FABRIK is a heuristic algorithm that implements simple operation iteratively for solving inverse kinematics [3]. Instead of using angle rotations, it updates the joint's new positions along a line to the next joint. FABRIK's main advantages are its simplicity, low computational cost, flexibility for different problems, and its effectiveness in solving closed loops or problems with multiple end effectors [4]. All the mentioned properties make FABRIK an excellent tool for the currently proposed algorithm. Moreover, unlike most other inverse kinematic methods that operate in a single iteration, FABRIK works in a forward and backward iterative mode, minimizing at each iteration the distance between the target and the end effector. The procedure depicted in Figure 3. First, the algorithm puts the end effector's new location, which equals the target's position (a). The previous joint's new position is determined in a line passing from the end effector and previous joint (b). This procedure repeats for all the other joints until reaching the base bone joint (c), (d). The next step is to do the backward algorithm. In the backward phase first, the base-bone joint steps back to its initial position (e). The following joint new position is determined in a line passing from its previous position and base-bone updated location, and all the procedure repeats, but this time from base bone to end effector (f).

In each FABRIK's step, the next joint's position is projected and re-oriented on the surface of a conic section related to the previous joints' motion zone. As depicted in Figure 4, a human arm is considered as a chain that the FABRIK algorithm applies to it. As shown in the figure, human joints can rotate in a determined region like a conic sec-

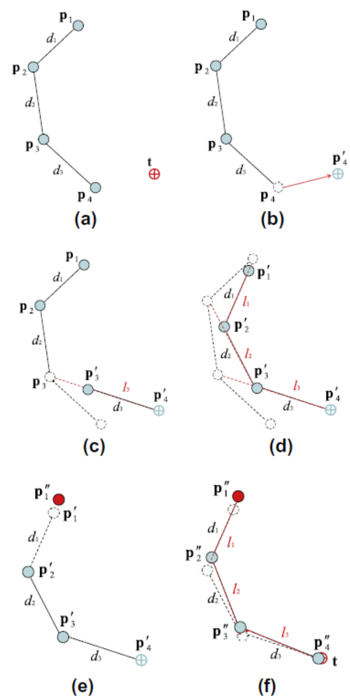

Figure 3: Steps of FABRIK algorithm for a simple chain. (a) to (d) shows the forward phase. (e) to (f) shows the backward phase. These two process continues iteratively. The picture adopted from [3].

tion (the grey region in Figure 4). By tightening or widening these motion zones, different solutions of FABRIK can be achieved [2].

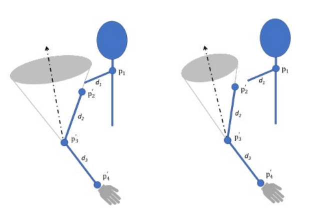

Figure 4: The grey cone shows the possible motion zone for each joint. In b, the joints motion zone is shrunk to adapt the FABRIK solver to finds its solution in restricted constraints.

We used the FABRIK method for the whole human kinematic chain, not just the arm. Solving it for the entire chain should consider the entire human body as a combination of multiple open and closed chains. The forward and backward phases of FABRIK applied to these chains, respectively. In Figure 5 first, the forward phase is adopted for arm's chain Figure 5-(a), then update the upper body's chain and lower body's chain Figure 5 -(b),(c). Finally, we apply the forward phase for the legs' chain. Afterward, in the backward stage, as depicted in Figure 6, the legs are positioned back to their original locations Figure 6-(a). The lower body and upper body joints' position are updated Figure 6 -(b),(c). Finally, the backward phase is applied to arms Figure 6-(d). These two procedures are applied iteratively until the arm's end effector; in this case, the hands can reach the workpiece.

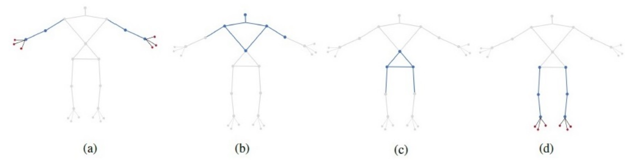

Figure 5: Order of solving forward phase of FABRIK algorithm for whole human chain [2]. The steps from a to e showing the steps in the proposed algorithm for solving inverse kinematic problem [3].

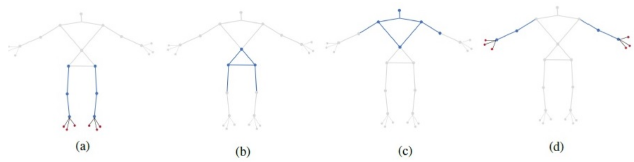

Figure 6: Order of solving backward phase of FABRIK algorithm for whole human chain [2]. The steps from a to e showing the steps in proposed algorithm for solving inverse kinematic problem.

In this part, we described the FABRIK procedure, and its capabilities to solve an inverse kinematic problem for the full human body. In the following, we describe the role of FABRIK in the ergonomic optimization algorithm.

3.3.2. FABRIK role in optimization algorithm

FABRIK investigates the possibility of reaching a target within the new joints limitation that is derived from the previous section. FABRIK, as stated before, can propose its solution based on the joints constraints. i.e., the solution is offered by FABRIK is the human chain configuration that each joint moving in its defined zone. It is evident that if the joints' motion zone is restricted a lot, human chains cannot move, and consequently, FABRIK cannot find a solution. The idea of restricting the joints' motion zone is depicted in Figure 4 only for the arm. We apply the same procedure for all human joints. In Figure 4, the grey cone shows the joints' allowed motion zone, which is dictated by the constraints that we applied in each optimization algorithm's iteration. Joints' motion range is derived with the logic described in optimization methodology. As the algorithm cannot go further, this final solution is announced as the most ergonomic possible posture that can be achieved. It will deliver to the operator through the interface.

4. Results

To assess this hypothesis's validity and be assured that the developed algorithm [29] works efficiently, and its result is independent of the one or two specific worker's posture, we used the joints position, and orientation of thirty different poses consist of 3 (activities) x 10 (subjects) from the dataset [16]. All the dataset activities are selected to remind the activities in an industrial working environment. Using the data acquisition device like Microsoft Kinect, the participants were asked to do the activity (for example, grab an object from a shelf). They got no prior instruction about doing the task, so they did the job in their way, and in this way, in addition to grabbing the task constraints, the object's pose (for example, the pose of the item on the shelf), the participant's joints' pose data could be captured. All the measurements were done on ten different people (five males and five females) aged between 20 and 35, one subject left-handed. After capturing the pose data, their original REBA scores were calculated, then their ergonomic status evaluated, and if needed, the ergonomic optimization algorithm applies to them. Moreover, after using the optimization algorithm, their final REBA scores are measured. Their initial and final REBA scores' mean and standard deviation are conveyed in Table 1. To further evaluate the result, we used a T-test [39]. This test is a type of probable statistic used to determine if there is a significant difference between the means of two groups, which may be related to certain features. As the people in the dataset selected randomly, we can use their REBA scores as a random variable that t-test can be applied to its result. A t-test is used as a hypothesis testing tool, which allows testing an assumption applicable to a population. The t-test of these two values for initial postures and final postures for all the cases was compared. The significant change in these values shows the validity of the proposed algorithm. In the following, one sample of each case is shown for more clarification, and at the end, the result of applying the algorithm on all the ten people showed.

4.1. Case one: stack items in industrial environment

In this first action, stacking objects is considered as an example. By putting some items in a fixed pose, from ten-people asked to stack them. Moreover, their joints position and orientation are taken from the Microsoft Kinect sensor and are gathered in a dataset. In this stage, only by knowing the participant joints' pose we can evaluate the ergonomic condition by the REBA method. Moreover, knowing the fixed position and orientation of the items that need stacking, we have the task constraints data. In the time of accomplishing the participant's task, in the case of not ergonomic posture, i.e., the REBA score is higher than three. The ergonomic optimizer algorithm starts by reducing the total REBA score by one unit and evaluating this reduction's feasibility by the FABRIK algorithm. This reduction continues until the FABRIK cannot find a solution anymore. FABRIK's no more solution means that no other ergonomic posture is possible for the current task constraints. Finally, this optimized posture is proposed as a recommendation to the worker. In the Figure 7. The right picture shows a more ergonomic posture for doing the task. The left REBA score is four, while the right posture REBA score is two.

First, by putting some items in a fixed position in a room, the participants are asked to stack them. While they are doing the task, the Microsoft Kinect sensor captures their joints position and orientation. Each participant does the job in his/her way. Their joints' pose data are gathered for ergonomic analysis with the REBA method to evaluate their ergonomic condition. In this case, the first participant does the task so that his/her REBA score becomes 4. This number means that this way of stacking items can be ergonomically dangerous for the user. The optimization algorithm starts its optimization by reducing the REBA score by one unit and searches for the joints' limitations. By applying them, the user can continue his/her task more ergonomically. Moreover, in each reduction, the FABRIK algorithm checks the possibility of it. In this case (The first user) by reducing the abduction angle of the upper arm, the REBA score decreases by one unit and in the following, by positioning the wrist in a better position in the result of better positioning of the upper arm, the REBA score will decrease to 2 which showing the safe status of the user. In each step of reducing the REBA score, the possibility of the task's continuation under the new angles constraints is checked by the FABRIK, so we can be assured that accomplishing the task in this new way is possible for this user. The same analysis is done for the rest of the participants, and their initial stance and final posture's REBA values are compared.

Figure 7: The right picture shows a more ergonomic posture for doing the stacking items task. The model is from Rocketbox-libraries http://www.rocketbox-libraries.com

4.2. Case two: assembly items on a chair behind a table in industrial environment

For the second case, assembling objects on the table is considered as an example. Some assembly items are put on the table, ten-people are asked to sit behind a table and assemble them. The same procedure is applied to this group. Finally, the optimized posture for this action is computed by the algorithm. In Figure 8, the initial and corrected posture for the first subject is shown. The left REBA score is four, while the right posture REBA score is one.

After evaluating the first participant ergonomic status, the REBA score of four shows the dangerous posture that this participant is used for accomplishing the job. First, the algorithm reduces the REBA score to three, the joints constraints which are forced because of this reduction, modify the leg, and proposes the better positioning of legs behind

Figure 8: The right picture shows a more ergonomic posture for doing the assembly task.

a table. The algorithm goes for more reduction, the better positioning of the trunk is proposed by the algorithm and, in the following, upper arms are taken closer to the trunk. As a result, lower arms are also positioned in a more ergonomic location. Consequently, the overall REBA score is reduced from three to two and finally to one. The algorithm stops at this stage, and the most ergonomic possible posture for assembling on the table for the first subject is proposed. The same procedure is applied to the rest of the participants. Finally, their initial and final REBA values are compared with each other.

4.3. Case three: grab something from shelf in industrial environment

For the last action, grabbing an object from the shelf is considered as an example. The ten-people asked to take a box from the shelf. The box's position and orientation are fixed for all the participants. Joints position and orientation are gathered in a dataset. The same procedure is applied to them. Finally, an optimized posture is proposed as a recommendation to the worker. In the Figure 9, the initial and corrected posture by the algorithm for the first subject is shown. The same is done for all the other 10 participants, like two previous cases. On the right and left are the final and initial postures, respectively. The right picture shows a more ergonomic posture for doing the task. The left REBA score is three, while the right posture REBA score is one. After ap-

Figure 9: The right picture shows a more ergonomic posture for grabbing items from grounds.

plying the REBA method on the first participant, the REBA score of three shows a status that needs modification. First, by further leaning the trunk and reducing the knee degrees, a more ergonomic posture is achieved. By this reduction, the neck and upper arms are also getting a chance to be positioned more ergonomically according to REBA scores. By these modifications, the overall REBA score is decreased to two than one. The algorithm applies to the rest of the participants. Finally, their results are compared with the t-test in the following section.

5. Discussion

The histograms of final and initial REBA scores for the studied people are depicted in the Figure 10. It compares REBA values before vs. after applying optimization techniques for thirteen different situations, ten people in three different industrial activities. In the Figure 10 the grey and hashed bins show the histogram of REBA values after and before applying optimization algorithms while the solid and dotted lines show the kernel density estimationn (kde) [31] of REBA values after and before applying the optimization algorithm. The lower the score, the safer is the posture. The overlapped zone is also visible on the bottom with different opacity. These two dotted and solid curves show the REBA

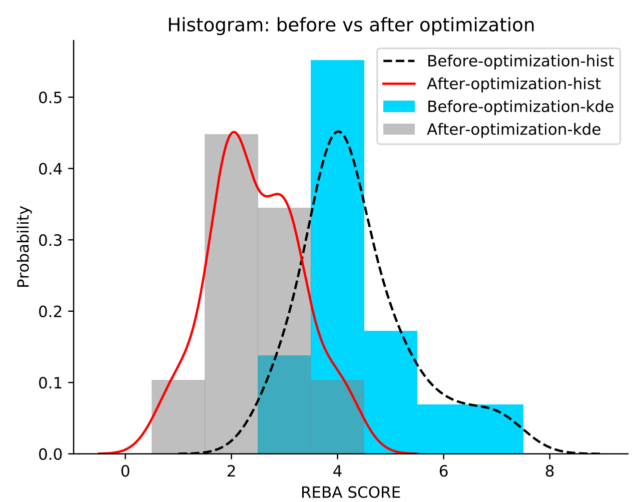

Figure 10: Comparing the histogram of before vs after optimization REBA values by hashed and grey bins. Comparing kernel density estimation of before vs after optimization REBA values by dotted and solid lines

values' probability density function in these two groups. These diagrams prove that the REBA values' distribution after the optimization algorithm shifted by two units to the left. This reduction also shows that the optimization algorithm could successfully reduce the REBA scores of the studied people. Moreover, this reduction designates an improvement in the ergonomic situation of postures after applying this algorithm. This result is not confined to one or two test cases. All the studied groups' ergonomic conditions improved after using this optimization algorithm. The statistical results like mean and standard deviation of the REBA values for

30 sample cases before and after applying the optimization algorithm are stated in Table 1. To further prove this improvement and indicate a considerable change between the two groups' ergonomic status before and after this optimization, we did the t-test [39] on this dataset and tested our hypothesis about this population. This test results in the critical value [5] of $2.465e-10$, which shows a significant difference between the ergonomic situation (REBA value) of a specified population due to applying the optimization algorithm.

Table 1
Postures' REBA score statistical result before and after applying the optimization algorithm on participants, these data also used for t-test SN: sample number, STD: standard deviation

Group	SN	STD	Mean
Before-Optimization	30	1.049	4.38
After-Optimization	30	0.827	2.45

As discussed in section 3.2, each posture can be defined by a REBA array that defines the ergonomic status of that pose. After solving the minimization problem based on the task constraints, we find an optimal pose with a new REBA array that defines this optimal ergonomic status. A distance between these two arrays can be considered a distance between two poses (the current pose and the optimal pose). The Euclidean norm measures the distance between the two arrays. For further experimental evaluation during the task for all the participants, Table 2 shows the changes in total REBA score relative to this Euclidean distance. In some cases, the result was the same; thus, there is an iteration. Besides showing the distance of two REBA arrays, the Euclidean distance implicitly shows changes in the joints' angle of two poses before and after optimization. As a result, the ideal case is to have more REBA reduction by the least changes in joints' angle or Euclidean distance. The lower the Euclidean distance relative to more REBA reduction means that the optimal pose is derived by little changes relative to the participant's current posture. Based on the REBA table, the maximum value for this Euclidean distance is 5.47. We see that for these participants, the REBA differences relative to their Euclidean distance place in an acceptable range. For example, for a REBA reduction of four, only the Euclidean distance of 2.24 happened, and this shows a minimum change in people configuration for placing in optimum posture.

Moreover, it is worth to know the algorithm's speed in solving the optimization problem and proposing the optimized posture for accomplishing tasks. The algorithm speed is measured for these thirteen cases. The average time to solve the algorithm is 0.55, with a standard deviation of 0.035. With a maximum time of 0.65 and a minimum of 0.45 seconds. These numbers show the stability of the algorithm in proposing the solution in different cases.

Table 2
Measured Euclidean distance of current participants' pose relative to optimal pose.

Euclidean distance	Difference in REBA	Number of iteration
1.73	2	7
1.41	2	3
2	1	2
2	2	4
1.41	1	2
1	1	3
2	3	3
1.73	3	3
2.65	4	1
2.24	4	1
2.83	1	1

6. Conclusion

The largest category of work-related injuries is related to musculoskeletal disorders. MSDs are caused mostly by doing repetitive movements in a nonergonomic posture many times. We proposed a generic algorithm that monitors the worker's attitude by the motion capture device and measures the joints' position and orientation to prevent this issue. Based on the task constraints, it can suggest the most ergonomic posture for accomplishing the task. To check the recommended posture's workability, we used the forward and backward, reaching inverse kinematic (FABRIK) to predict the worker's posture by employing the recommended posture. i.e., to see the feasibility of the proposed posture that is derived from the current algorithm. The proposed algorithm can be used in the control algorithm of collaborative robots or exoskeletons to consider ergonomics' concerns in workers' routines, which is considered the next step for this paper. The other task for future works is to consider dynamics forces and repetitive motions besides kinematic data as an input for the described optimization algorithm. Also, for assessing the ergonomic status of the workers' posture, we used the REBA assessment method, which is entirely modular and can be replaced by any other ergonomic assessment method that can give quantitative measures about the ergonomic status of the workers. This modularity of the algorithm makes it to be adaptable for any usage that needs optimal ergonomic posture. Also, the FABRIK algorithm is an excellent tool for predicting human behavior in real-time. The algorithm's validity is tested on a dataset of 10 people in 3 different cases and with different physical specifications to prove this algorithm's generality for different users. The validation phase results show the generality of the algorithm and its ability to propose a more ergonomic posture for a task in the industrial environment for any person with any body's morphology. One of this work's limitations is that this optimization algorithm is limited to discrete-valued ergonomic assessment metrics. Namely, only the ergonomic assessment methods that give quantitative measurement feedback can be used in this algorithm, such as REBA and RULA. However, we can reach the exact optimized point in the discrete optimization methods but require higher computational costs. We believe it is beneficial to use the discrete ergonomic metric equation to guide the continuous ergonomic metric equation's discretization.

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