Reassigning Construction Laborers based on Body Motion Analysis

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Abstract

Construction laborers perform multiple labor intensive and physically demanding tasks, which exposes them to the risk of work related musculoskeletal disorders. When construction laborers sustain these injuries, they are typically reassigned to other tasks. The body motion involved in carrying out the assigned task should have limited use of the affected body part(s). This has implications on the productivity and health of a reassigned laborer. Traditional approach to reassigning laborers are subjective and ignores the effect of the tasks on the affected body part. To address this limitation, an ergonomic analysis framework is proposed to quantify the risk factors associated with body parts during the execution of construction tasks, so as to enable the reassignment of construction laborers to tasks that will impose the least strain on the affected body part. Preliminary results are provided to demonstrate feasibility.

Keywords –

Construction laborers; Work-related musculoskeletal disorders; Reassignment; Wearable technology

1 Introduction

In the construction industry, Work-related musculoskeletal disorders (WMSDs) make up about 37% of injuries experienced by the workers [3]. Of the injured workers, construction laborers are most likely to develop WMSDs because of the physically demanding nature of their tasks. The type of WMSDs usually sustained from these tasks are soreness and pains, carpal tunnel syndrome, sprains, strains and tears, and tendonitis (Figure 1). The most prevalent of these injuries are sprains, strains and tears. Figure 2 shows the rate of occurrence of this injuries amongst laborers in comparison to the overall construction industry. BLS [4] also shows that construction laborers are injured at the rate of 79.5 musculoskeletal disorders (MSDs) per 10,000 workers, while the overall construction industry's musculoskeletal injury rate is 49.2. Thus improving work safety practices of construction laborers is important.

Construction laborers perform a variety of tasks including removing debris and possible hazards, loading and unloading materials, bracing and unbracing scaffolding, digging and backfilling trenches and compacting earth to prepare for construction [5]. When they are injured, their supervisors typically reassign them to less strenuous tasks. This allows the laborer to continue working on the job and prevents the contractor or subcontractor from taking on a lost time injury on their experience modification rate (EMR) safety rating. Reassigning workers to less strenuous task is highly subjective and error-prone, as there is no means of verifying that the worker will be able to assume the postures required for the task. Each of these injuries affect different parts of the body and also restricts the movement of one or more limbs. Table 1 shows the types of MSDs and affected parts of the body. The degree of restriction on the limbs is determined from the postures and each posture is constrained by different muscle loadings, body and joint rotations [2], degree of bent of body parts [8], exposure to vibration and repetitive movements. Thus, to ensure that an injured worker remains on the job, while also being productive, it is important to reassign him to tasks that poses the least risk to the affected body part(s). Construction tasks are characterized by postures that involves multiple risk factors, this poses the following questions: (1) How can we reassign workers to tasks that poses the least risk to their injury, while also ensuring that they are productive? (2) How do we quantify the long term effect of this task on their health? This is important because there is currently no metric for assessing the potential effect the assigned tasks on the affected body part (or existing injuries) and potential of the injured worker to be productive on the reassigned task.

In-spite of the fact that a growing number of workers in the construction industry have WMSD, previous industry and research efforts have been focused on risk assessment [2,6,12,13,15] and prevention of WMSDs [10,14,16]. There have been limited efforts on how to keep injured workers on the job while also maintaining productivity. Furthermore, there have been limited focus on unskilled workers such as construction laborers and helpers.

The objective of this study is to propose an ergonomic analysis framework to (1) quantify the risk factors of postures, body parts and joints of tasks typically performed by construction laborers; (2) reassign injured construction laborers to tasks that will impose the least strain on the affected body part.

Table 1. MSDs and affected body parts [7,11]

MSD	Common affected body parts
Carpal tunnel syndrome	Fingers, hands, wrists
Tendonitis	Shoulder, waist
Soreness and pains	Neck, back, joints
Sprains and Strains	Joints (ankle, knee, elbow, shoulder), neck, lower back

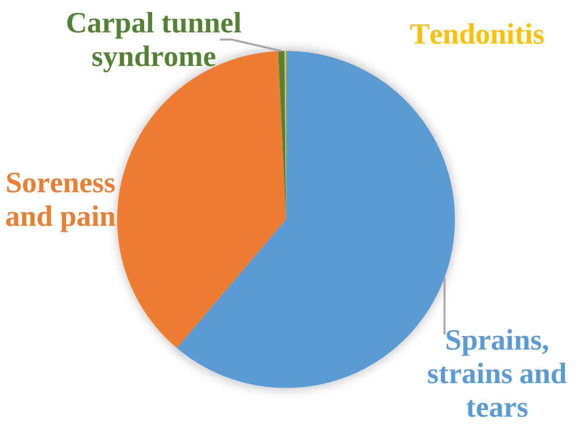


Figure 1. Proportion of occurrence of WMSDs amongst construction laborers

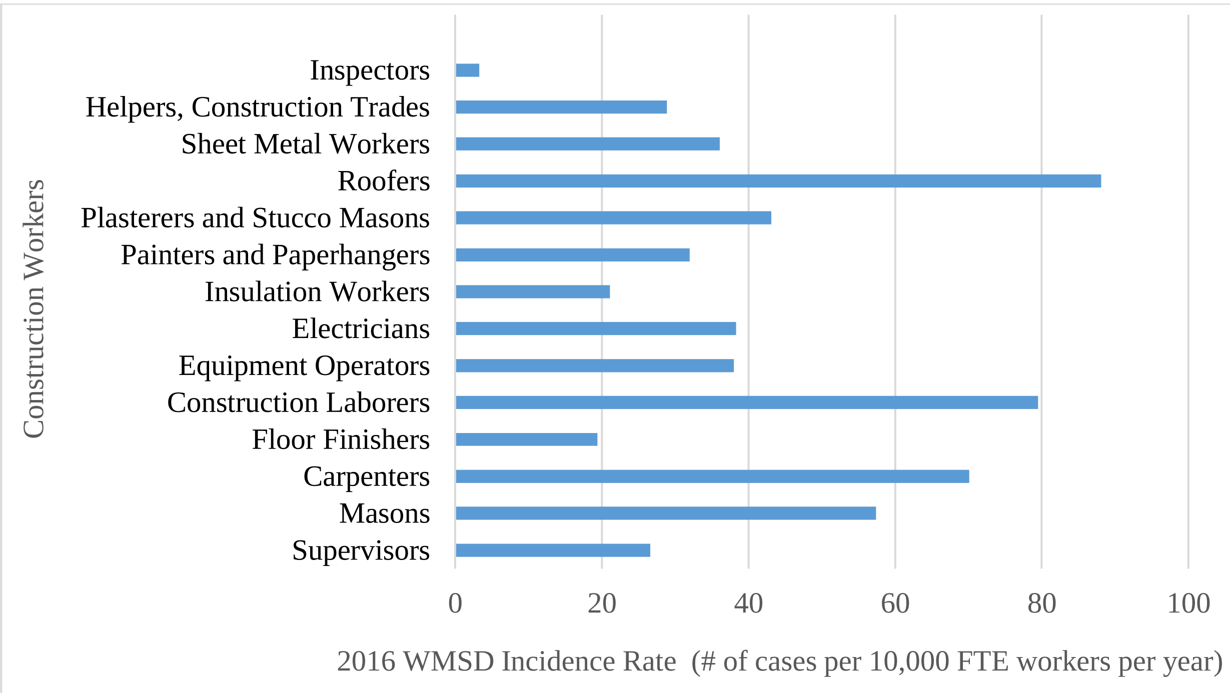


Figure 2. Rate of WMSDs amongst selected construction occupations for 2016

2 Framework for Construction Worker Reassignment

The proposed framework, shown in Figure 3, consists of the following stages: (1) Creating 3D human motion model to imitate tasks that construction laborers typically perform. In addition to this, actual body motion will also be generated from the lab and construction sites using image and component based sensing systems e.g. depth cameras and inertia measurement unit. Since it may not be physically feasible to capture all construction tasks, some of the tasks will be generated in the simulation model and complimented with the physically obtained motions; (2) Import the motion data from the body sensors into the 3D visualization platform; (3) Export the body posture data (from stage 1 and stage 2) from the 3D visualization into a database; (4) Store exported data in a database. The exported data are task, postures, associated body parts and loadings, joint angles and loadings; (5) optimize the data associated with each body part and joints (from stage 4) to predict construction tasks with the least risk to the affected body part; (6) Display suitable the task(s) and ranking(s)/associated effects on the affected part.

Depending on how the human body motion is being generated, the input could be the task process, task schedule, load, work environment and workspace design (i.e. if using the 3D Model) or the input could be the raw data depicting the body motion.

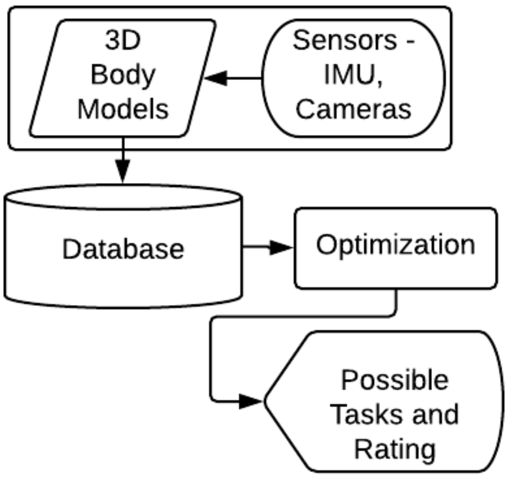


Figure 3. Framework for construction trade reassignment.

3 Preliminary Results

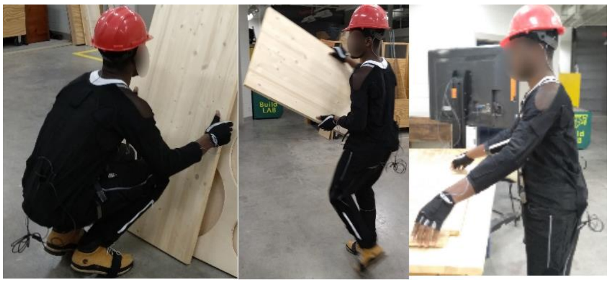
3.1 Sensing System

This study used the Inertia 3DSuit motion capture suit (Figure 4), which is a full body human motion capture system. The suit is based on 3D miniature inertial motion unit (IMU) sensors which includes tri-axial accelerometers, gyroscopes and magnetometers. The suit is equipped with an on-board signal processor and data fusion algorithm which extracts data from the sensors, processes the data and outputs the orientation of the sensors. The suit consists of 18 orientation sensors connected to a mobile bus processing unit which powers and receives data from the sensors via a serial protocol. The received data is wirelessly transmitted to any computer at the rate of 60Hz, to create a body skeleton of the tracked individual.

Figure 4. Inertia 3DSuit infrastructure showing the location of the IMU sensors.

3.2 Case Study

To illustrate the performance of the proposed framework, this case study describes a scenario of a worker who has knee disorder. The site manager has the option of reassigning the worker to one of the following three tasks: stacking wooden boards (Lifting); laying plumbing pipes (Plumbing) and installing lighting systems (Electrical). As part of an initial data collection, we designed an experiment to assess the motions, postures, body parts and joints of a subject while performing all three tasks in a laboratory setting. Prior to commencing the experiment, the computer was connected to a Linksys wireless router so as to aid capturing of motion data. The subject wore the suit and connected it to the wireless router. On calibrating the suit, the subject commenced each of the tasks. For example, while lifting and stacking the boards, the motion was recorded. The motion produced three key repetitive postures – Squatting, walking, and bending (Figure 5). At the end of the task, the recording was stopped and the data was saved. This process was repeated for each of the tasks. The extracted data was analyzed using Biovision software and exported as a .bvh file, which was visualized using Autodesk MotionBuilder. Figure 6 shows a typical bvh file. The posture and joint angles for each task was generated using Autodesk MotionBuilder.

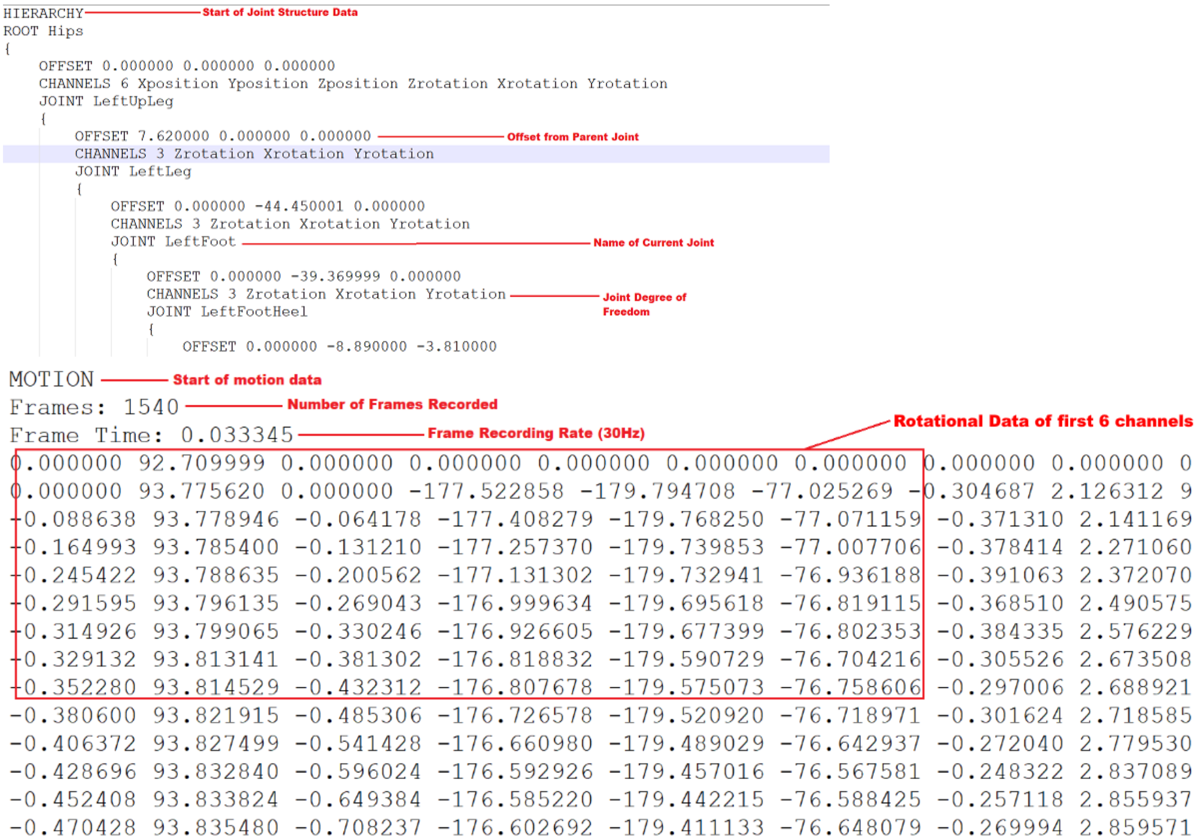


(a) Swatting (b) Walking (c) Bending

Figure 5. Lifting Task Postures

3.3 Results

Table 2 shows the results of the case study discussed in the preceding section. The table shows the angles of the postures and affected joints of the three tasks.



```
HIERARCHY
ROOT Hips
{
    OFFSET 0.000000 0.000000 0.000000
    CHANNELS 6 Xposition Yposition Zposition Zrotation Xrotation Yrotation
    JOINT LeftUpLeg
    {
        OFFSET 7.620000 0.000000 0.000000
        CHANNELS 3 Zrotation Xrotation Yrotation
        JOINT LeftLeg
        {
            OFFSET 0.000000 -44.450001 0.000000
            CHANNELS 3 Zrotation Xrotation Yrotation
            JOINT LeftFoot
            {
                OFFSET 0.000000 -39.369999 0.000000
                CHANNELS 3 Zrotation Xrotation Yrotation
                JOINT LeftFootHeel
                {
                    OFFSET 0.000000 -8.890000 -3.810000
MOTION
Frames: 1540
Frame Time: 0.033345
0.000000 92.709999 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0
0.000000 93.775620 0.000000 -177.522858 -179.794708 -77.025269 -0.304687 2.126312 9
-0.088638 93.778946 -0.064178 -177.408279 -179.768250 -77.071159 -0.371310 2.141169
-0.164993 93.785400 -0.131210 -177.257370 -179.739853 -77.007706 -0.378414 2.271060
-0.245422 93.788635 -0.200562 -177.131302 -179.732941 -76.936188 -0.391063 2.372070
-0.291595 93.796135 -0.269043 -176.999634 -179.695618 -76.819115 -0.368510 2.490575
-0.314926 93.799065 -0.330246 -176.926605 -179.677399 -76.802353 -0.384335 2.576229
-0.329132 93.813141 -0.381302 -176.818832 -179.590729 -76.704216 -0.305526 2.673508
-0.352280 93.814529 -0.432312 -176.807678 -179.575073 -76.758606 -0.297006 2.688921
-0.380600 93.821915 -0.485306 -176.726578 -179.520920 -76.718971 -0.301624 2.718585
-0.406372 93.827499 -0.541428 -176.660980 -179.489029 -76.642937 -0.272040 2.779530
-0.428696 93.832840 -0.596024 -176.592926 -179.457016 -76.567581 -0.248322 2.837089
-0.452408 93.833824 -0.649384 -176.585220 -179.442215 -76.588425 -0.257118 2.855937
-0.470428 93.835480 -0.708237 -176.602692 -179.411133 -76.648079 -0.269994 2.859571
```


Figure 6. Typical bvh file

Table 2. Task, posture, affected joints and angles

		Angles								
		Postures								
		Task 1 - Lifting			**Task 2 - Plumbing**			**Task 3 - Electrical**		
Body Parts	**Joints**	**Swatting**	**Bending**	**Walking**	**Swatting**	**Bending**	**Standing**	**Reaching**	**Bending**	**Climbing**
Left Leg	Left Ankle	27.78	22.81	19.41	34.19	13.63	8.04	5.56	8.14	24.86
	left knee	15.72	133.75	17.67	29.05	50.51	63.45	7.21	13.94	56.38
	left hip	99.50	98.13	24.78	86.58	107.62	44.15	10.88	28.58	26.78
Right Leg	Right Ankle	32.64	32.76	11.35	27.98	8.30	9.97	6.27	6.84	9.12
	Right knee	18.40	44.36	18.35	18.78	55.13	13.84	8.26	39.09	14.70
	Right hip	115.09	113.87	10.08	114.2	106.98	14.04	11.49	51.97	40.30
Left hand	Left Shoulder	18.56	30.37	32.40	25.29	57.08	4.48	39.81	24.79	20.58
	Left elbow	25.74	67.86	15.97	77.67	13.25	8.82	72.32	68.55	46.61
	Left wrist	7.23	51.11	65.94	6.26	25.36	10.79	39.66	11.30	17.68
Right hand	Right Shoulder	34.06	35.45	51.27	29.64	60.10	9.47	53.94	23.82	8.27
	Right elbow	57.42	54.43	8.68	34.66	22.79	14.44	114.94	16.23	12.62
	Right wrist	28.94	36.69	5.78	79.57	39.06	34.44	77.42	56.60	50.75
Spine	Upper Spine	9.27	27.22	47.15	34.10	37.20	3.57	23.90	8.10	14.11
	Lower Spine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Neck	Neck	19.22	7.63	2.99	3.49	20.65	16.81	28.24	34.91	4.89
Hips	Hips	49.87	43.92	18.49	37.18	87.02	6.01	5.003	18.46	37.23
Head	Head	19.22	7.63	17.83	3.49	20.65	16.81	28.24	34.91	4.89

The preliminary data consists of only the angles at the body joints for 3 tasks, as such, optimization is not required. For the purpose of identifying tasks with the least risk to the knee or that will not aggravate the existing condition of the knee, the angle at the knee will need to be compared for all the tasks. Andrews, et al. [1] identified that the risk of a disorder can be measured in terms of angle made by the affected part of the body i.e. the angle made by the knee in relation to the normal status i.e. when a worker is standing – when there is minimal physical stress on bones and muscles [9]. The larger the angle made by the knee, the higher the risk of injuries. Table 3 shows the risks for different knee flexion angles [1].

Table 3. Suggested sizes for measurement of knee flexion

Ergonomic Risk	Knee Flexion
Low	0^0-30^0
	30^0-60^0
	60^0-90^0
High	$>90^0$

From Table 2, by comparing the angles for the left and right knee, the 'Electrical' task appears to have the least angles and the least risk. However, in relation to Table 3, the risk to the knee of the laborer is still significantly high.

4 Conclusions and Future Work

This paper proposes a framework that uses human body motion analysis to reassign construction laborers. The framework uses body motion captured using 3D motion simulation software and motion sensors to capture tasks typically performed by laborers. The associated motion data of these tasks such as postures, affected body parts and joints, loadings on the body parts and joints, condition of the task environment, will be captured and stored for analysis. For any injured body part, these data will be optimized to predict construction tasks with the least effect on affected body parts. Preliminary work using a proprietary body suit has been presented.

For future work, a taxonomy of body motion of construction laborers for different construction tasks, will be developed.

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