

MACHINE LEARNING TECHNIQUES FOR MOTION ANALYSIS OF FATIGUE FROM MANUAL MATERIAL HANDLING OPERATIONS USING THREE-D MOTION CAPTURE DATA

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ABSTRACT:

Industrial Revolution 4.0 is described as the interconnection of Information, Communications Technologies (ICT), and factory ground employees. Workers in the fabric coping with industry are regularly problem to repetitive motions that reason exhaustion (or fatigue) which leads to paintings-associated musculoskeletal problems (WMSDs). The maximum common repetitive motions are lifting, pulling, pushing, carrying and taking walks withload. In this studies records is accumulated as time-stamped movement statistics the usage of infrared cameras at a fee of 100Hz whilst a topic performs one of the repetitive motions (i.E. Lifting). The facts is a combination of xyz-coordinates of 39 reflective markers. This effects in 117 facts points for each frame captured. Since these motions occur over time for a duration of time, this facts is used as

input to a time-collection device studying (ML) model inclusive of Recurrent Neural Network (RNN). Using this version, this paper evaluates system learning techniques, primarily based on RNN, to assess the fatigue aspect as a result of repetitive motions.

Keywords— industrial revolution 4.0, manual material handling, fatigue, machine learning, recurrent neural network, motion capture

I. INTRODUCTION

Mechanical Revolution 4.0 speaks to the improvement of the community oriented incorporation among people and machines utilizing Artificial Intelligence (AI), Internet of Things (IoT), Collaborative Robots (Cobot), and information examination [1][2][3]. The material taking care of industry can profit by this incorporation by building 'shrewd' material taking care of procedures. The inspiration for this paper is to improve the security of the administrators in the material taking care of industry.

Manual material dealing with tasks extend from lifting, pushing, pulling, conveying with burden, and holding of items for a length of time. These manual activities are regularly performed drearily all through an undertaking, which can make the administrator experience exhaustion. When the administrator encounters weakness their exhibition diminishes. In the event that they don't have a satisfactory time to rest between task, they start to abuse their body causing wounds which may build up a business related musculoskeletal issue (WMSD).

One approach to lessen the abuse of a laborer's body will be to screen the administrator's developments utilizing AI to identify exhaustion. This arrangement will help decrease wounds or longterm impacts from the manual material taking care of (MMH) activities. Earlier work have use AI to gauge exhaustion in practice movements utilizing movement catch information or wearable sensors and a Rate of Perceived Exertion scale (RPE). Utilizing existing writing, a period arrangement utilizing Recurrent Neural Network (RNN) based methodologies known as LongShort Term Memory (LSTM), and Gated-Recurrent Unit (GRU) will be considered for foreseeing the degree of weariness of a laborer during a material dealing with activity.

II. RESEARCH BACKGROUND AND RELEATED WORK

A. Industry 4.0

The proposed task is identified with Industry 4.0 (I4.0), otherwise called Cyber-Physical Production Systems (CPPS) [1][2]. I4.0 was first presented in 2011 and is the current modern upheaval that includes robotization and information trade. The fundamental thought for I4.0 is to deliver a 'Brilliant' processing plant to give the capacity for people and CPPS to cooperate utilizing the mix of Artificial Intelligence (AI), Internet of Things (IoT), or potentially information investigation [1][2][3]. I4.0 targets expanding profitability by

shortening the creation and conveyance time of the mechanization procedure [3]. Having 'more astute' manufacturing plants will empower organizations to lessen costs, increment effectiveness and diminish people being supplanted by robots as they have an essential impact material dealing with process [1][2][3].

Another inspiration is to improve the manual material dealing with security where administrators are performing redundant manual activities. When performing dreary manual activities, administrators may encounter exhaustion however will proceed to work bringing about the abuse of their musculoskeletal framework, prompting wounds and human blunder [4].

B. Issues Faced By Manual Material Handling Operators

1) Fatigue

Weariness, as indicated by the writing, is characterized as the weakness of an individual's ability or execution [5][6][7][8]. Weakness can prompt various side effects including distress that may influence the individual's engine work; low engine control (expanding response time); and decrease in physical quality [7]. Further, deficient recuperation can expand danger of damage, increment human mistake, and abatement work productivity [7][8]. In the long haul, on the off chance that weariness levels keep on expanding, at that point it can form into business related musculoskeletal issue bringing about expanded laborer's pay claims and lost days [4].

2) Work-related Musculoskeletal Disorder (WMSD)

Business related musculoskeletal issue are common in assembling elements with dreary work [9]. As indicated by the U.S. Branch of Labor, Bureau of Labor Statistics [10], 20,990 specialists in the control of workers, stock and material movers showed MSD or 'ceaseless' weariness, which was the biggest occupation in the rundown. Albeit ergonomic enhancements have been happening in the business (i.e., machines doing the truly difficult work), the administrators despite everything must recurrent manual activities which builds the odds of creating WMSD. Improvement of WMSD is likewise subject in enormous part, to the skeletal

muscles not having enough recuperation time subsequent to being actuated from taking care of overwhelming burdens or from inappropriate stance [11][12]. Laborers may likewise encounter dreary strain damage in their upper appendages (arms, shoulders, hands, and neck) and lower back [9][12].

C. Motion Capture

Movement catch was imagined to assist speed with increasing the activity procedure [13]. Movement catch is generally utilized today in gaming and the film business. Movement catch is characterized as the chronicle of developments of an article, at high recurrence, in a true setting by following the situation of focal points on the item [13][14]. There are different following advancements utilized for movement catch, they incorporate acoustical, inertial, attractive, mechanical and optical frameworks [13][14]. The Acoustical Systems utilize sound transmitters and mouthpieces set on explicit areas to assess the situation of the focal points. Inertial movement catch frameworks utilize an inertial sensor (containing an accelerometer and spinner) and depend on increasing speed and precise speed [14]. Attractive based movement catch frameworks utilize a lot of receptors to acquire the attractive field given by the joint position, points and direction on the body. Mechanical following frameworks are the most seasoned and least difficult technique for catching movement by utilizing potentiometers to gauge joint direction uprooting at each point. Optical marker following frameworks are partitioned into two classes: inactive and dynamic markers. The uninvolved markers are intelligent pointers connected to a point of enthusiasm on the on-screen character. Aloof marker positions are triangulated by utilizing the estimations caught from infrared fast camera reflections off the marker, delivering 2D directions of the information. Exclusive programming is used to figure 3D directions of the markers [13]. Then again, dynamic markers use LED markers that radiate their very own light as opposed to mirroring a light. There are likewise optical frameworks which don't utilize markers. These are known as optical marker-less following frameworks and use PC vision calculations.

D. Machine Learning

AI is a subset of Artificial Intelligence (AI) which permits a framework to get information and

produce a yield dependent on that information. AI is separated into three classes: regulated, unaided and support learning. With the end goal of this exploration, just the regulated and unaided strategies will be investigated for making an AI model to anticipate movement and weakness in a redundant manual material taking care of activity.

1) Supervised Learning

Directed AI picks up information from the utilization of past and present information utilizing marks to foresee future occasions. The names signify the arrangement that the anticipated yield ought to be. This technique basically contrasts the got outcomes and the real and anticipated that outcomes should figure the exactness of the framework. As indicated by [15] administered learning falls into probabilistic classifiers, and straight classifiers. Probabilistic classifiers are known as a generative classifier, in which the classifier gains from the created information and assessments the dispersion of the model to anticipate the concealed information (for example Gullible Bayes, Bayesian Network, Markov). Straight classifiers utilize the direct mix of highlights expected to bunch them into bunches that have a similar element esteem.

2) Unsupervised Learning

In contrast to regulated, solo strategies are utilized on non-ordered and non-marked information meaning the capacity of the framework is to acquire the concealed examples from the unlabeled information to distinguish the yield. This procedure doesn't contain the genuine outcome, however it can in any case gain information from the perception of information. The techniques related with solo is the utilization of highlight extraction strategies like Principal Component Analysis (PCA) or utilizing a Neural Network with an autoencoder [16].

E. Machine Learning Using Motion Capture for MMH

Movement catch innovation is as of now being utilized to gather information to give ergonomic assessments to material taking care of tasks [17][18][19] with just a not many that utilization AI [20][21]. For this area just the writing identified with AI and MMH will be talked about further. The creators in [20] made an answer utilizing Artificial Neural Networks (ANN) to

foresee act from movement catch information from the HUMOSIM dataset for non-dull manual material dealing with assignments. It is critical to recognize the lifting stance to evaluate the danger of physical damage from the MMH errands. The creators utilized the underlying and last hand areas of the MMH undertakings to prepare the model with 2D and 3D organizes. While their answer, contrasted with reverse kinematics, is equivalent in execution, the blunder rate in anticipating the stance was around 5–20% [20].

In [21], the creators investigate the utilization of three arrangement calculations; Linear discriminant examination (LDA), k-closest neighbor (k-NN) and multilayer feedforward neural system (MFNN) for arranging manual material dealing with undertakings utilizing inertial movement information or potentially in-shoe pressure estimations. A self-sorting out guide (SOM), a neural system dependent on a solo grouping calculation with 1,024 neurons in 32x32 matrix as the AI procedure was utilized on highlights extricated utilizing a sliding window of ten casings acquiring five enlightening insights: mean, difference, min, max, and kurtosis. For the informational collections that contain IPM yields, head segment investigation was additionally used to lessen the components of the element vector. They accomplished an exactness rate >90% yet their information size was moderately little with just ten members. Every one of the undertaking characterizations were performed exclusively on every member.

These arrangements applied AI to assess and characterize the developments being done in MMH errands. They don't utilize movement catch information to assess the weariness factor actuated by the MMH developments directed for each kind of movement. Along these lines, the objective for this venture is make AI model that utilizations movement catch information to foresee/recognize movements in MMH errands and anticipate the exhaustion level of an administrator to lessen the introduction to WMSD chance components.

III. DATA COLLECTION

The information assortment procedure will imitate manual material taking care of activities in an ongoing situation. A gathering of members will play out a progression of manual material dealing with errands, these undertakings will basically

impersonate an administrator working in a genuine material taking care of framework. For every administrator situation, a trial will be directed at different statures. Tasks, for example, lifting/bringing down, pushing/pulling, conveying, and strolling include loads with an alternate weight dependent on sexual orientation and tallness attributes.

Since this exploration includes human subjects, the test strategies must be endorsed by the Texas State University Institutional Review Board and educated assent was gotten from the members before leading any analyses. Every member is viewed as an administrator for the information assortment process. Every member will wear a brilliant article of clothing known as a Hexoskin® Shirt that contains body sensors inside the dressing, combined with the Hexoskin® Smart Device [22]. The Hexoskin® Smart Device will screen the biometrics (for example pulse, breathing rate, calories consumed) of the member which will at that point be put away and handled in the cloud once it is synchronized to the Hexoskin® stage [22]. Alongside the Hexoskin® Shirt, subjects will likewise have 39 intelligent markers connected to their skin or garments utilizing twofold sided sticky tape with each intelligent marker appended to a joint on the body.

A gathering of Qualisys cameras (six Oqus 510, two Miquis M3 [23]) are utilized to follow intelligent markers (39 markers) appended to the member. The cameras produce constant xyzcoordinates as an element of time at a pace of 100 Hz (100 casings for each second) while the subject plays out the activity. As the member is playing out the doled out development, they are asked each moment their RPE utilizing the Borg scale from 6 (No effort) to 20 (Maximal effort) [24].

IV. MOTION AND FATIGUE PREDICTION APPROACH

Foreseeing when the administrator will get exhausted from the dreary movements will build the work security of an administrator in the MMH business. Along these lines, utilizing the information gathered from the investigations an AI model will be made to foresee when the weariness of the administrator will undoubtedly happen while they are playing out their administrator task. Having the administrator set aside some effort to

recuperate will at that point diminish the potential for musculoskeletal issue related with dreary movements and increment human wellbeing. This segment will examine the various techniques that will be utilized to foresee weariness utilizing the movement catch information. Weakness forecast right now perceiving the movement being satisfied and having the option to foresee the exhaustion at that point to tell the administrator to rest. The objective is to anticipate the exhaustion during the manual activity by recognizing the uprooting that happens when the administrator begins to change their stance as they begin to encounter distress. This implies the sort of movement must be recognized and furthermore be anticipated with the goal that adjustments moving can be associated to the various movements.

Fig. 1 shows the progression of the procedure for one of the movements (leg lifting), this procedure will be rehashed for different movements also. The procedure will begin with the contribution of information, at that point preprocessed and split for preparing and testing. When the information is part the AI model will be prepared and tried. A short time later the model will be assessed and afterward the hyperparameters are tuned utilizing the matrix search strategy. Ultimately, when the model produces worthy outcomes for anticipating movement and recognizing weariness, the model will be tried utilizing inconspicuous information comparing to the movement type.

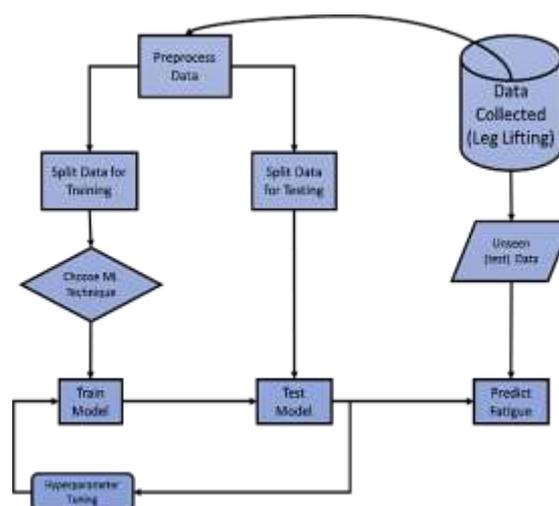


Fig. 1. Machine Learning Motion and Prediction Process

A. Preprocessing Data

Fig. 2 shows the techniques for the preprocessing of the information before preparing and testing the model with the movement catch estimations. With preprocessing, the objective is to organize the information for the AI model to use during the learning procedure of the preparation. Fig. 2 outlines the two choices for preprocessing the crude movement catch information. The thoughts appeared in Fig. 2 are motivated by past work led moving investigation on weariness, and movement forecast [16][24-28][31-33].

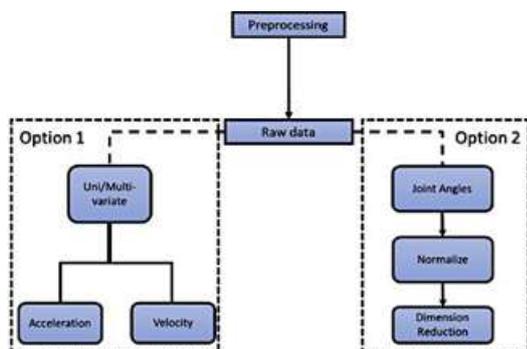


Fig. 2. Preprocessing Methods of Motion Capture Data

Choice 1 is the univariate/multivariate examination of the crude 3D movement catch information and the markers' speed and quickening. Alternative 2, the joint edges are determined from the 3D movement catch information and furthermore decreased in dimensionality. The two choices utilize an alternate organization for the information to have the option to discover what group the AI calculation can use to deliver a practical movement and have the option to foresee weakness from the movements.

1) Univariate/Multivariate

Univariate is the investigation of a solitary variable which right now just a solitary measurement either x, y, or z from the markers. Not at all like univariate, multivariate is the examination of utilizing at least two factors which right now be the utilization of every single positional datum from every one of the markers. Expanding on the ongoing work of [25], three distinct methodologies can be executed utilizing the two kinds of examination (univariate/multivariate) with the crude information. In [25], they perform measurable movement examination between the first and last development of the wrists, elbows,

and shoulders utilizing, xyz (1D and 3D), speeding up and speed to demonstrate any adjustment in development because of weakness. The outcomes demonstrated that the wrists and elbow indicated an expansion in speed when lifting and bringing down. Taking the first and last development additionally indicated that the left wrist and elbow had significant contrast in run, with the left having the most change since the people were correct given.

The primary methodology will assess the relocation of movement utilizing one single marker spoke to [25]. The following methodologies will grow the work and consider the utilization of the considerable number of markers spoke to by its xyz to assess the movement of the entire body as opposed to utilizing one single marker for the ML model. Three diverse preprocessing approaches that will be assessed are portrayed beneath:

a) The primary methodology will utilize a univariate examination of the speed or the increasing speed of a solitary marker spoke to by either the x, y, or z measurement. This implies there may be one element to prepare the model. Utilizing this methodology will be the underlying advance to test which heading to take from every marker that will show relocation of the particular movement.

b) The subsequent methodology utilizes every one of the 39 markers' xyz information, which means there will be 117 (39*3) values. The 3D speeding up and speed for every bearing will likewise be determined for every marker, delivering just 39 qualities. Utilizing the xyz information, 3D speeding up and 3D speed will, along these lines produce 156 highlights which will be viewed as the entire body set of highlights

c) The third methodology joins univariate factors to shape a multivariate configuration. Utilizing one variable for each marker (x, y, or z esteem) with their separate increasing speed and speed esteems will be utilized as the highlights. Subsequently, an aggregate of 78 highlights will be utilized for preparing the model, diminishing the quantity of highlights contrasted with the subsequent methodology.

2) Joint Angles

The movement catch camera framework following the 39 latent intelligent markers appended to the body speak to a progression of joints. [26] utilized

joint points of the lower leg, knee, hip, lower and chest area to break down exhaustion on a consistent level and gauge the expansion of weariness while playing out a squat exercise. They utilized a parametric-concealed Markov model (PHMM) for demonstrating the joint points over the term of the activity with a ceaseless parameter to show the movement change because of weakness.

Since the movement catch estimation position is made out of 3D xyz-organizes, the joint edges should be figured for 16 recognized joints utilizing reverse kinematics as appeared in [26]. The information will be standard standardized for each subject's arrangement of edges, by registering the mean (μ) and standard deviation (s) from the preparation information. Utilizing those estimations, the testing and preparing information can be standardized by utilizing $y(t) - \mu/s$ with $y(t)$ being viewed as the present information esteem at t time. The joint edges will be utilized for assessing exhaustion by estimating the variety in flexion of each joint. For instance, in a lifting exercise the body twists the chest area forward. The advancement in exhaustion can be estimated by distinguishing the change (increment or decline) in body twisting [26].

Another preprocessing procedure that could be valuable to extricate key highlights inside the information gathered is known as measurement decrease or highlight extraction. For this reason, it will be known as measurement decrease since the objective is to diminish the measure of information utilized as the information with the goal that it will likewise diminish runtime. As per [16] Principal Component Analysis (PCA) has recently been utilized on a period arrangement to lessen dimensionality yet saving the highlights with the most noteworthy variety in the information. When utilizing a measurement decrease calculation on the information, the design is to save the greater part of the data based of the fluctuation of the information and utilizing fewer highlights. For instance, in [27] they gain execution for grouping between 'weariness' versus 'nonexhaustion) in walk movements by utilizing PCA and Fourier Transformation (FT).

B. Training & Testing Data

When the information has been preprocessed it must be part into two areas one for preparing and one for testing to make an AI model. Since the

information gathered contains information for male and female, the parting of information into preparing set and test set must be summed up to the general populace. Embracing what was done in the writing [16][28][29], three diverse getting the hang of setting will be explored different avenues regarding. The principal getting the hang of setting will be to utilize the information from every one of the members (male and female) with the suspicion that a portion of the members will have comparative movement examples and weariness. The subsequent getting the hang of setting will be to make a model for a particular member by letting their information alone for the learning procedure and just utilizing the other member information. In conclusion, the third and straightforward alternative will be to make a customized model for each subject utilizing just their information for the learning procedure. The presumption with this is the subject will have interesting developments related with their own reaction to expanding exhaustion. For each picking up setting, when the information has been decided for the procedure, it will be part by a 70% preparing - 30% testing split.

C. Machine Learning Techniqe and Algoirthim

1) Supervised Learning Technique

For administered figuring out how to foresee yield target esteems must be distinguished for the preparation and testing of the model. For this usage the RPE scale known as the Borg scale, got from each subject in the information assortment process, will be utilized as the objective worth (name). This worth will be interjected inside each edge for every moment since the RPE is taken each moment. Utilizing this scale, the objective will be to foresee weakness as indicated by the Borg Scale number given by the member as done in past work [26][27][28][29].

2) Unsupervised Learning Technique

The solo execution method will be actualized by utilizing the joint edges. Since PCA will be utilized in the preprocessing this will be viewed as the solo usage and will be utilized with the AI calculation.

3) Recurrent Neural Network Time Series Approach

Since this is a period arrangement expectation issue an answer will be to utilize an intermittent neural system. RNN is a kind of neural system (NN)

where the associations between hubs structure a succession of information [30]. RNN is a NN that utilizes inward state (memory) to recall from past perception and be utilized for foreseeing the time-subordinate arrangement. The capacity of NN to be utilized for directed and unaided learning legitimizes the utilization of RNN with the preprocessing techniques talked about.

A RNN basically utilizes the info information and its past yields to make the expectation which is what is expected to foresee the exhaustion dependent on past movements. Lamentably, the RNN will in general experience the ill effects of transient memory; the system experiences either a disappearing or detonating inclination, which means the system will make some troublesome memories to convey past perceptions. When preparing a RNN, as the slopes are determined when back spread through the prior layers, the inclinations to refresh the system loads abruptly become excessively little (evaporating angle) or excessively enormous (detonating inclination) [31].

To conquer these issues two mainstream RNN based arrangements that function admirably with time-arrangement anticipating are known as Long Short-Term Memory and Gated Recurrent Unit which have been utilized for foreseeing the movement however not anticipating weakness moving [32][33][34]. LSTM and GRU use doors to deal with the substance of the memory in the NN [31][35]. LSTM utilizes an information door, an overlook entryway, and the yield entryway. The info and overlook entryway will deal with the interior state which settles on the choice about what to store and when to eradicate [31]. The GRU additionally utilizes entryways like LSTM however it utilizes two doors rather than three [35]. There is an update door that controls the progression of data that decides the amount of the past perception should be passed to the future and a reset entryway that chooses the amount of the past data to overlook. The GRU is only a less difficult adaptation of LSTM.

Since it is demonstrated that RNNs can anticipate human movement, consolidating the capacity to foresee movement with weariness examination of movement it is conceivable to foresee weakness for a particular material taking care of activity, consequently, the AI method proposed will be founded on RNN systems. The models that will be

utilized are LSTM, 3-Layer LSTM, 5-Layer LSTM, and GRU.

V. CONCLUSION

In the material taking care of industry, weariness happens from how a lot of exertion is being utilized by the administrator, alongside the recurrence and length playing out the manual taking care of work. As the dreary movements are being led from an administrator, these exercises lead to body weakness which thus prompts wounds or human blunder. Consequently, an answer that can gauge the exhaustion level dependent on the movement removals when they happen will expand the human wellbeing in the business is proposed.

VI. FUTURE WORK

Future work right now be to convey the movement and exhaustion forecast AI model to a certifiable situation in the MMH business. In the production line floor of the MMH business it won't be reasonable to set up an optical marker movement catch framework because of the space taken to set-up the framework and the procedure to get the information. Along these lines, the information won't be gathered utilizing an optical marker movement catch framework however rather will be an inertial movement catch framework which will be perfect for coordinating in the production line floor of the MMH business.

Inertial movement catch (IMC) frameworks give adaptability of recording information contrasted with optical frameworks. IMC framework utilize low-power, remote transmission fit inertial sensors which are otherwise called inertial estimation unit (IMU). IMU carries conveyability to the movement catch process by having the option to be effectively moved to numerous situations. Right now, the laborers will be required to wear an inertial estimation unit to follow the position and development of the MMH assignments [20][21][28]. A continuous checking of the MMH administrator can be executed by utilizing the information transmitted by the IMU appended on the laborer, as the contributions to the ML calculation

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