

Harnessing Deep Learning for Precise Postural Analysis: Insights from Yogic Pose Research

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ABSTRACT

With the rapid rise in the growing adaptation of artificial intelligence and deep learning in healthcare spanning from analytical studies to diagnostic and interventional practices, the world is witnessing not only the transformation of the once impossible into reality, but also the remarkable precision with which these innovations are being implemented. The current study focuses on exploring the recent status in achieving technological adaptation to musculoskeletal analysis through the yogic practices along with drawing the reader's attention towards the unattended limitations in the recent trends adapted in the following years of adaptation of AI in postural analysis through yoga practices followed by a suggestive future scope of innovative practice.

Keywords: Pose detection, pose estimation, yoga pose assessment, pose precision feedback, yoga kinematics, deep learning

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INTRODUCTION

Antisthenes, a pupil of Socrates, famously said, 'The art of learning is to learn how to unlearn.' In today's world, with the rise of artificial intelligence and deep learning, guided learning has increased in popularity, alongside the Indian philosophy of yoga.

AI supports practitioners and instructors by providing data-driven insights to correct postures, helping them achieve perfection in their goals. It also enhances yoga pose identification, detection, assessment, estimation, and regression/prediction outcomes.

The application of AI in postural identification/recognition, detection, assessment,

estimation, and regression/prediction through yoga pose follows this architecture:

1. Data input
2. Data Pre-processing
3. Generating features
4. Feature extraction
5. Model training
6. Data optimisation

AI ARCHITECTURAL ADVANCEMENTS IN POSTURAL ANALYSIS THROUGH YOGIC PRACTICES

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The research enhancements explored in the field of synergistic AI and yogic practices with a future-oriented approach towards holistic well-being have been reviewed in detail through the current paper for future scope and reference, following in detail each level of the AI application architecture in yoga practice as enumerated above.

1. YOGA POSE DATA INPUT

Machine learning is used to analyse data inputted into yoga. This data can be gathered through visual data from images, recorded or real-time video, sensor-based methods, or text prompts. Smart yoga mats and haptic feedback devices can also be used to collect data.¹

The global surge in external monitoring systems to enhance machine learning was driven by the need for real-time feedback on yoga pose detection, which has become increasingly popular since the global pandemic of COVID-19 through the yoga pose estimation system that primarily employs computer vision to detect potential landmarks on the human body and classifies them according to specific yoga poses.²

Few of such system models include

- The Blaze-pose model that is employed to localize body joints detecting 33 key points covering various body parts.²
- Hybrid systems like the Media-pipe model are utilized for yoga pose image detection through real-time feedback, calculating the angles between the joints of the user³ and open pose for yoga pose recognition with higher accuracy.⁴
- The open pose system uses a multi-stage approach to estimate the pose through key points in the body using a body part detector and a graphical model-based approach.⁵
- The Kinect sensor uses a depth camera and a model-based approach to estimate the pose.⁵
- The generative adversarial networks (GAN), a type of deep learning model with a generator and a discriminator, use 2D images to generate samples from learned distributions, and the discriminator distinguishes between the generated sample and the real one. For example, to address any incorrect yoga pose, the GAN takes the input of detected key points from the incorrect yoga pose and generates corrected key points representing the ideal pose.⁵
- Deep Yoga, a deep learning model training a convolutional neural network (CNN) using data set of accurate yoga pose images from the practitioner's body, followed by using an angular approach to determine and classify poses from the angles between vectors in a skeletonized image.⁶
- Pose Net, a deep machine learning model used for yoga gesture detection and pose detection with surroundings and clothing variations.^{7,8}

- Adaboost interface system recognizes depth, colour, body of a seated user in wheelchair posture.⁹
- IoT based yoga posture identification system using deep convolutional neural network (DCNN) and a low resolution infrared sensor based wireless sensor network (WSN) with the help of logistic regression finds out the person's body angles and with the body angles it finds out the yoga position the particular person is doing.¹⁰
- Modular generative neural network synthesizes new poses using training pairs of images and poses taken from human action videos.¹¹
- Long short-term memory (LSTM) is a type of recurrent neural network(RNN) trained towards learning long term dependencies involving sequential or time series data.¹²
- SURF is a image detector and descriptor used for various image transformations.¹³

2. YOGA POSE DATA PRE-PROCESSING

The data collected from various sources in real world settings often contains many transcription errors, discrepancies which needs to be mitigated through a followed process of:

Data harmonization which includes standardization and categorization of the collected data.

Handling missing data includes either excluding the missing data which might reduce the data size for accuracy in model training or using imputation approach such as regression analysis or deep learning to fill in the missing data.

Data resampling includes aligning of the data in two ways i.e. down-sampling which means to simplify the data while keeping the essential information and up-sampling which means to capture the finer data

Data filtering involves isolating the interference from other signals.

Data warping primarily includes removing the noise and enhancing the true target signals, for example improving the image features if necessary or scaling of image for better quality.¹⁴

To improve the quality of image data, image processing is carried out using digital computers to run algorithms on digital images. This process is known as *possessiveness image processing*.

Another image pre-processing methodology is *Gaussian Blur or Gaussian smoothing* where masking of an image is done by 'Gaussian function' to reduce image noise and detail it. This technique creates a smooth, blurred effect, reminiscent of an image seen through a translucent screen. The advantage of such a technique is that the yoga posture in low light becomes more evidently seen and processed.³

However, to build an efficient deep learning model for improving yoga pose estimation, preprocessed images or videos can be used to extract features for model training.

3. FEATURES GENERATION AND EXTRACTION

Taking the reference from the recent advances in the data input to deep learning mentioned above, the 'features' of the data represent the processed data containing information related to the target output. In terms of yoga pose estimation process, the 'features' are taken as key points, joint angles, preprocessed or real time images or videos.

The current limitations in the deep learning process has been observed through 'key point detection' thereby hampering key point generation and extraction. In response to it, a model was proposed by Jayasurya J et al.(2023) on real time detection and classification of yoga pose using Tensor-flow Move Net which detects 17 key points with its two variants i.e. *Lightning prioritizing* performance and *Thunder* focusing on accuracy that runs fast and accurate in real time with 30FPS and the accuracy obtained from the model training was 99%. With many pose estimation models available through computer vision like media pipe detecting 33 key points, Pose net detecting 17 key points and Open pose detecting 25 key points, the challenges are still existing and are mainly faced at obtaining the level of accuracy and performance of the machine learning.^{15,16}

Having said that, the feature extraction process involved the process of *pose estimation* which refers to the computational process of determining the configuration of a person's body in a given posture which can be done by single pose where a single body is estimation or multi pose estimation where multiple bodies are estimated.¹⁷ Convolutional neural networks (CNNs) enable image processing for pose estimation through two approaches: the *bottom-up approach*, which estimates body joints first and then groups the data to form unique poses; and the *top-down approach*, which first detects a boundary box and then estimates the body joints.

To estimate a human pose by locating the joints in the body skeleton from an image, *human body modelling* is essential. A human body can be modelled as

Skeleton-based /kinematic-based model i.e. represented by key points and not by the texture or shape of the body.

A planar-based or contour-based model, represented by multiple rectangular boxes, yields the body outlines and shows the shape of the body.

Volumetric-based model, i.e., represented by a three-dimensional (3-D) model of well-articulated human body shapes and poses.

The various pose estimation models in the deep learning solutions are Epipolar Pose, Open Pose, Pose Net, and Media Pipe.

Epipolar Pose creates a 3D model out of a 2D image data input.

Open-pose is a 2D approach to pose estimation where a degree of association is created between the various parts of the body and the human skeleton is evaluated.

Pose Net analyses images from video data input, followed by generating visual vector generation from the image and mapping the featured vectors, and finally, by using regression, creates an estimated pose.

Media-pipe predicts key points from the extracted pose region of interest (ROI) of the colour image input.

According to a study conducted by Mohan KD et al. (2022), it was observed that Media-pipe has better accuracy than Pose-net (80% accuracy), Open-pose (70% accuracy), and EpipolarPose (50% accuracy).¹⁹

5. MODEL TRAINING

Modern artificial intelligence is capable of learning complex patterns and relationships in data for various tasks. This is served by *Neural Networks*.

The architecture of neural network is referred as Feed Forward Neural Network (FNN), also known as multi-layer perceptron(MLPs). These are versatile models using classification, regression and function approximation tasks. The FNN architecture includes an input layer, which receives functions from the input data, a hidden layer consisting of neurons/units/nodes which primarily reads the deviated data and an output layer which creates the final prediction.

In the working of neural networks functioning, apart from the above explained forward propagation management, there exists loss calculation where loss functions are calculated after the FNN output layer creates the prediction, followed by the *back propagation* which includes calculation of the gradient of loss functions with respect to the network parameters. In short, the network uses back-propagation to update the weights and biases of the neurons in the network, minimizing the loss. This is followed by *Gradient descent optimization algorithms*, that updates the parameters in the direction that minimizes the loss.

The processed data or features further work on descriptive, predictive, or prescriptive models based on the algorithm's architecture, such as clustering algorithms that group similar data to their concerned functions from model objective boundaries, regression algorithms that estimate a function from the input features and continuous outputs, and classification algorithms that identify discrete features for the objective of the model functioning.

Following the process of forward propagation, loss calculation, back propagation, and parameter updation, the model begins training. During training, the network learns to extract relevant features from the input data. Once trained, the performance of the FNN is evaluated. In this manner, relevant data for FNN deep learning is processed, with 20% going for testing and 80% for training.²⁰

To categorize the detected yoga poses through comprehensive analysis of pose estimation, a comparative

study conducted by Meghana JH et al. (2025) among the machine learning classifiers, including Support Vector Machines (SVM), Random Forest Classifier, and K-nearest Neighbors (KNN) classifiers utilizing the key points extracted from the pose estimation models, concluded that Random Forest attained 95-100% accuracy in detecting and classifying the yoga poses included in the study as compared to SVM and KNN. This result is also supported by another study result conducted by Vani A et al(2022) where performance of different ML model was compared to conclusively find out Random Forest with 0.89 accuracy compared to Logistic regression (0.86 accuracy), Gradient Boosting classifier (0.84 accuracy) and Ridge classifier (0.82 accuracy).^{3,18}

Another similar study was conducted by Jyothika S. et al. (2023), comparing four machine learning classifiers, namely , Random Forest, Support Vector Machines (SVM), XGBoost, and Decision Tree, and two neural network classifiers, i.e., CNN and LSTM, and the demonstrated results showed that XGBoost outperformed by 95.14% accuracy, followed by CNN and Random Forest (94.7% accuracy), LSTM (93.82% accuracy), SVM (92.05% accuracy), and Decision Tree (86.75% accuracy).¹³

CURRENT LIMITATIONS

- Blaze pose, the model architecture of the Mediapipe developed by Google for yoga pose estimation is although has proved out with its accuracy in detecting key points and estimating the yoga poses with its approach to human pose tracking by running only for the first frame for data input and deriving pose region of interest (RoI) followed by identifying 33 key points for the derived RoI of subsequent frames but with a major disadvantage of detecting the position of a single person within the image or video input. It can not identify the position of multiple persons.²¹
- Use of wearable sensor for yoga pose estimation has faced challenges by limited acceptance due to discomfort, privacy concerns or perceptions of surveillance. (Ereena B et al; 2024) and is considered to be impractical as compared to computer vision approach with better future scope.²¹
- Lack of cohesive integration between machine learning and computer vision approaches with primary focus on generic application followed by neglect towards in-depth analysis required for system optimization effectiveness.¹²
- LSTM model of sequential analysis of yoga poses has faced varied limitations of showing inaccuracies especially in handling the continuous and varied nature of yoga postures.¹²
- There still exists limitation in recognition and feedback generation to highly complex advanced yoga poses accurately.¹¹
- Large data sets requirement and labeling them with high accuracy is still a challenge being time consuming and expensive.

- Lack of interpret-ability by machine learning models with limitations in data classification process making debugging an obstacle to system improvement.²²
- Hardware high energy consumption continuously running for deep learning and reduction to the battery life of portable device along with expensive computational costs serves as another major limitation.²²⁻²³
- Lack of proper sampling i.e. expert yoga practitioners for the system training, validation and deep learning so as to improve the data accuracy and quality of deep learning process.

FUTURE SCOPE

The future scope of practice to yoga pose estimation using machine learning should focus on

- Improvising on quality data input by selecting purposive samples including expert yoga instructors and practitioners to carry out yoga pose estimation and focus on segmented deep learning techniques to human body anatomy and categorized yogic practices analysis from focused inputs.
- Bio-mechanical analysis followed by Postural analysis with deep learning should be promoted to make the neural network learn the correct and accurate joint alignments effectively addressing the major drawing to the system processing challenges.
- Enhancing the deep learning model training by engaging pose estimation with real time feedback by AI powered virtual assistants.
- Developing adaptive algorithms that can customize feedback on individual body types and motor skill levels progressing over time
- Training on multi pose tracking models to strengthen real time expert feedback system
- Collaborative model designing with expert feedback from various professionals to strengthen the deep learning model processing.
- Creating virtual trainers with immediate feedback from deep learning models and collaborating them to create a strong machine learning model.
- Creating more environment-aware machine learning models with intelligent feedback mechanisms and with easy cost effective accessibility revolutionizing the ancient philosophy of yogic practices, teaching and wellness experience.

CONCLUSION

Artificial Intelligence should never replace human intelligence, but instead, it should be created to work hand in hand with human expertise, building more efficiency in the field. The philosophy of data learning through artificial intelligence should follow the building of human intelligence and cognitive learning with innovation and efficiency, allowing man and machine to function hand in

hand. The remarkable growth in machine learning since the COVID-19 pandemic, particularly in the area of yoga pose estimation, should not divert attention from the core philosophy of Yoga. Instead, it should be used and integrated into every possible innovation and research in the future.

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