

Yog Pose Coaching System using ML

A Project Report

***Submitted in the partial fulfillment for the award of the degree
of***

BACHELOR OF ENGINEERING

COMPUTER SCIENCE

Submitted by:

SACHIN SAINI– 21BCS6025

SHIVANGI RAI–21BCS6155

Under the Supervision of:

Mr. Raghav(E16302)



**CHANDIGARH
UNIVERSITY**
Discover. Learn. Empower.

CHANDIGARH UNIVERSITY, GHARUAN, MOHALI -140413,

PUNJAB

MONTH & YEAR

AUGUST 2024

BONAFIDE CERTIFICATE

Certified that this project report Yog Pose Coaching System using ML is the BONAFIDE work of

SACHIN SAINI

UID:21BCS6025

SHIVANGI RAI

UID:21BCS6155

Who carried out the work under my supervision certified further that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation based on which a degree or award was conferred on an early occasion on this or any other candidate.

(Signature of the Head of the Department)

(Signature of the Supervisor)

PRIYANKA KAUSHIK

HEAD OF THE DEPARTMENT

*Department of Computer Science Engineering
(AIT-CSE)
Chandigarh University
NH-95 Chandigarh-Ludhiana
Ludhiana*

Mohali, Punjab (INDIA)

Mr. Raghav(E16302)
SUPERVISOR

*Department of Computer Science
Chandigarh University
NH-95 Chandigarh-*

Mohali, Punjab (INDIA)

CERTIFICATE FOR EVALUATION

College Name: Chandigarh

University

Branch: Computer Science

Engineering.

Year/Semester: 2024-Sem 7

S. No	Name of students who have done the project.	Title of the Project	Name of the supervision with designation
1	SACHIN SAINI (21BCS6025)	YOG POSE COACHING SYSTEM USING ML	Mr. Raghav(E16302)
2	SHIVANGI RAI (21BCS6155)		

The report of the project work submitted by the above students in partial fulfilment for the award of Bachelor of Engineering degree in Computer Science Engineering of Chandigarh University were evaluated and confirmed to be the reports of the work done by the above students and then evaluated.

INTERNAL EXAMINER

EXTERNAL EXAMINER

DECLARATION

In accordance with the requirements for the Degree of Engineering in Computer Science Engineering, Department of Computer Science Engineering, University Institute of Engineering, Chandigarh University, Gharuan, Mohali, Punjab.

*We present this report entitled “Yog Pose Coaching System using ML”. This report has been prepared under the supervision of **Mr. Raghav(E16302)**, Department of Computer Science Engineering, University Institute of Engineering, Chandigarh University, Gharuan, Mohali, Punjab.*

We declare that the work presented in this report is our report except as acknowledged in text, footnotes and weblinks, and that to our best knowledge, this material has not been submitted in whole or in part, for a degree for this University or any other Institution.

SACHIN SAINI
(21BCS6025)

SHIVANGI RAI
(21BCS6155)

Annexure-4 (A typical specimen of table of contents)

TABLE OF CONTENTS

<i>1. INTRODUCTION</i>	<i>4-5</i>
<i>2. LITERATURE SURVEY</i>	<i>6-7</i>
➤ <i>EXISTING SYSTEM</i>	<i>8</i>
➤ <i>PROPOSED SYSTEM</i>	<i>9</i>
<i>3. PROBLEM FORMULATION</i>	<i>10-11</i>
<i>4. RESEARCH OBJECTIVES</i>	<i>12</i>
<i>5. METHODOLOGY</i>	<i>13-14</i>
<i>6. TENTATIVE CHAPTER PLAN FOR PROPOSED WORK</i>	<i>15-28</i>
➤ <i>CHAPTER 1: INTRODUCTION</i>	<i>15-17</i>
➤ <i>CHAPTER 2: LITERATURE REVIEW</i>	<i>17-18</i>
➤ <i>CHAPTER 3: BACKGROUND OF PROPOSED METHOD</i>	<i>19</i>
➤ <i>CHAPTER 4: METHODOLOGY</i>	<i>20-26</i>
➤ <i>CHAPTER 5: EXPERIMENTAL SETUP</i>	<i>26</i>
➤ <i>CHAPTER 6: RESULTS AND DISCUSSION</i>	<i>27-28</i>
➤ <i>CHAPTER 7: CONCLUSION AND FUTURE SCOPE</i>	<i>28</i>
<i>7. REFERENCES</i>	<i>29-34</i>

LIST OF FIGURES:

Sr.no	Name	Page no.
1.	Figure 1	33
2.	Figure 2	36
3.	Figure 3	37
4.	Figure 4	39
5.	Figure 5	44
6.	Figure 6	45

Abstract

This paper proposes a **Yoga Pose Coaching System** utilizing **Machine Learning (ML)** techniques to offer real-time feedback and guidance on yoga postures. The system aims to assist users in performing yoga poses accurately by analyzing body movements and suggesting corrective actions. The key components of the system include a **pose detection model**, a **pose evaluation module**, and a **feedback generation module**.

We leverage **computer vision** algorithms and **deep learning models** to detect and classify yoga poses from video input. The core of the system is based on **pose estimation models** such as OpenPose, MediaPipe, or PoseNet, which track key points of the human body to extract skeletal data. This skeletal data is then processed by an ML model trained on a labeled dataset of various yoga poses, allowing the system to identify the user's current pose and evaluate its correctness.

The **pose evaluation module** calculates discrepancies between the user's pose and predefined standards for each yoga position. It uses a **similarity scoring algorithm**, such as **cosine similarity**, to compare the user's key point angles with those of expert practitioners. If the deviation exceeds a predefined threshold, the system identifies the specific body parts needing adjustment.

The **feedback generation module** provides real-time verbal and visual guidance, highlighting corrections needed to improve alignment and balance. This module leverages **natural language processing (NLP)** for generating contextual feedback, ensuring users receive personalized coaching. The system is designed to adapt over time by incorporating user performance data, thereby improving feedback precision through a **reinforcement learning loop**.

The proposed Yoga Pose Coaching System offers a promising approach to making yoga practice more accessible and effective, catering to users of all skill levels. It can be integrated into fitness apps, virtual reality experiences, or home workout platforms, enabling users to receive personalized guidance without the need for a live instructor.

1.INTRODUCTION

Yoga is a popular physical and mental practice that promotes flexibility, strength, and relaxation. However, achieving the correct alignment in yoga poses can be challenging, especially for beginners and individuals practicing without direct guidance from an instructor. Incorrect postures not only reduce the effectiveness of the practice but can also lead to muscle strain or injury. As the demand for remote and self-guided fitness solutions continues to grow, there is a pressing need for intelligent systems that can provide real-time feedback on exercise form and technique.

This paper presents a **Yoga Pose Coaching System** utilizing advanced **Machine Learning (ML)** and **Computer Vision** technologies to offer users real-time guidance on their yoga practice. The system leverages **pose estimation models** to detect key body points from a video feed, enabling accurate identification and assessment of various yoga postures. By analyzing the user's skeletal data, the model can evaluate their alignment and provide detailed, personalized feedback, assisting users in achieving the correct form and reducing the risk of injury.

The core of the system integrates state-of-the-art **deep learning models** such as **OpenPose**, **MediaPipe**, or **PoseNet**, which have demonstrated high accuracy in human pose estimation tasks. These models extract key joint coordinates from video frames, forming a skeletal representation of the user's body. The skeletal data is then fed into a pose classification model trained on a diverse dataset of yoga postures, allowing the system to recognize and assess the user's current pose.

To ensure effective coaching, the system compares the detected pose against expert pose templates using a **pose evaluation module**, which analyzes joint angles and body alignment. If discrepancies are identified, the **feedback generation module** provides corrective suggestions using both visual markers and verbal cues. By leveraging **Natural Language Processing (NLP)**, the feedback is delivered in a user-friendly manner, offering clear and actionable guidance.

The proposed system aims to enhance the user experience by offering a **virtual yoga assistant** capable of adapting to individual progress. It has the potential to be integrated into mobile applications, wearable devices, or augmented reality (AR) platforms, making yoga practice more accessible and effective for users of all skill levels. Through this intelligent approach, the Yoga Pose Coaching System seeks to bridge the gap between self-practice and expert-led instruction, empowering users to refine their yoga techniques and achieve better result.

2.LITERATURE SURVEY

The integration of **machine learning** and **computer vision** into fitness and wellness applications, particularly in the domain of **yoga pose detection**, has gained significant attention in recent years. Various studies have explored the application of these technologies to enhance training, prevent injuries, and provide real-time feedback to practitioners. This section reviews relevant research related to pose estimation, yoga classification, and related methodologies.

1. Human Pose Estimation with Deep Learning

Human pose estimation is the foundation for detecting yoga poses, where the objective is to accurately identify the positions of key body joints. Early work in pose estimation was based on traditional computer vision techniques, including feature extraction and 2D pose models. However, with the advent of **deep learning**, the accuracy of pose detection has drastically improved. Models like OpenPose (Cao et al., 2018) and DeepPose(Toshev and Szegedy, 2014) revolutionized pose estimation by leveraging deep convolutional neural networks (CNNs) to detect body landmarks. OpenPose, in particular, became one of the most widely used frameworks for multi-person pose estimation, marking a significant milestone in human pose detection.

2. Yoga Pose Detection Systems

Several studies have specifically focused on yoga pose detection. **Feng et al. (2017)** proposed a method that used computer vision techniques to classify yoga poses based on skeletal joints and key body points. Similarly, **Ishikawa et al. (2018)** developed a yoga pose recognition system using deep neural networks to identify poses from live video streams. These systems often rely on **pose classification models** to determine the alignment and correctness of yoga poses.

Wang et al. (2020) presented a CNN-based approach to detect 16 different yoga poses and demonstrated its potential for real-time feedback and corrections. Their system achieved an impressive accuracy rate of around 85%, but faced challenges with complex poses and occlusion.

In another study, Zhao et al. (2019) combined pose estimation and motion tracking to enhance yoga pose detection, where they used a 3D skeletal model to track joints in a more robust manner across multiple frames. The use of 3D information helped mitigate issues with pose occlusion and provided more reliable feedback during complex movements.

3. Deep Learning Models for Pose Detection

Deep learning methods, particularly CNNs and Long Short-Term Memory (LSTM) networks, are increasingly being applied for accurate and real-time pose detection. CNNs are effective in extracting spatial features from images, while LSTMs handle temporal sequences, making them suitable for analyzing dynamic movements in activities like yoga. For example, Li et al. (2018) utilized CNN-LSTM hybrid models for human action recognition, which successfully handled continuous sequences of poses, similar to the transitions seen in yoga.

Another relevant approach is the combination of 2D and 3D models to improve the robustness of pose estimation under varying conditions. Pavlakos et al. (2017) demonstrated how integrating depth information with RGB images improved the accuracy of pose detection by providing additional spatial context, which is particularly valuable when detecting poses in cluttered environments.

4. Challenges in Yoga Pose Detection

While progress has been made in pose detection, challenges remain in terms of handling occlusions, pose variations, and real-time processing. Yoga poses are highly varied, and the complexity increases as the practitioner moves through dynamic sequences. For instance, in poses like the **Crow Pose** or **Headstand**, where limbs are frequently occluded, pose estimation becomes much more challenging. Existing pose estimation systems also struggle with complex or high-speed transitions between poses, which are common in yoga practice.

Real-time performance is another area of concern. Pose detection models, particularly those based on CNNs and LSTMs, require substantial computational power. Achieving accurate results with low latency is essential for providing real-time feedback during yoga sessions.

Data scarcity is another issue, as many publicly available datasets primarily focus on general human pose estimation, which may not capture the specific range of poses in yoga practice. Custom datasets, such as **Yoga-82** (Zhou et al., 2017), have been developed to address this, but they still need to be expanded to cover more diverse poses and practitioners.

5. Applications of Yoga Pose Detection

Yoga pose detection systems have a variety of applications, including injury prevention, personalized training programs, and remote instruction. Real-time feedback systems enable practitioners to improve their posture, reducing the risk of injuries. Moreover, these systems can be integrated into virtual or augmented reality environments for immersive training experiences, as seen in systems like **YogaAR** (Kwon et al., 2020), where virtual instructors guide users through poses in real-time.

Another promising application is **remote yoga instruction**, where pose detection models can assess a practitioner's alignment and provide feedback to instructors who are not physically present. These systems not only make yoga more accessible but also democratize access to expert training, particularly in underserved or remote regions.

6. Evaluation Metrics in Pose Detection

Common evaluation metrics for pose detection systems include classification accuracy, precision, recall, and F1 score, as well as the confusion matrix, which offers insight into the performance of the model across different pose categories. Models that focus on yoga pose detection need to address metrics such as the percentage of correctly identified poses, the ability to handle pose transitions, and real-time feedback accuracy. Learning curves (loss and accuracy curves) are used to assess the model's generalization capabilities and training efficiency, ensuring that the system continues to improve over time.

2.1. EXISTING SYSTEM:

The field of yoga pose coaching and evaluation has seen a rise in digital solutions, ranging from mobile apps and wearable devices to more advanced computer vision-based systems. These systems aim to guide users in their yoga practice, helping them improve their posture and alignment. This section reviews the existing systems and technologies currently available, highlighting their capabilities, limitations, and underlying methodologies.

1. Mobile Applications for Yoga Coaching

Several popular mobile apps have emerged, offering guided yoga sessions and basic feedback on poses:

Down Dog, **Yoga for Beginners**, and **Daily Yoga** provide structured classes with video demonstrations, audio instructions, and progress tracking. However, these apps typically do not analyze user performance; they rely on self-assessment, which limits their ability to provide personalized feedback.

Asana Rebel and **Yoga Studio** integrate pre-recorded video content of expert practitioners demonstrating poses. These apps may include pose correction tips, but the feedback is static and generic, lacking real-time analysis of user performance.

2. Wearable Devices and Motion Sensors

Wearable devices like smartwatches, fitness trackers, and motion sensors have been adapted for yoga practice, offering limited feedback based on motion data:

- **Fitbit** and **Apple Watch** include basic yoga tracking features, such as measuring heart rate, session duration, and estimated calorie burn. However, these metrics do not provide information about pose accuracy or form.
- **Yoga Motion Sensors** (e.g., **SmartMat**, **Nadi X Yoga Pants**) use embedded sensors to detect body alignment. The **SmartMat**, for instance, uses pressure sensors to analyze weight distribution and provide feedback on balance, while **Nadi X Yoga Pants** have embedded sensors that vibrate to indicate incorrect alignment.

3. Computer Vision-Based Yoga Coaching Systems

Recent advances in **computer vision** and **machine learning** have enabled the development of systems that use cameras (e.g., smartphone cameras, webcams) to analyze user poses:

- **YouTube AI Yoga Videos**: Some yoga channels have started experimenting with AI-driven video analysis. They provide on-screen pose detection using models like **MediaPipe** or **PoseNet**, displaying a skeleton overlay to help users see their

alignment.

- **Pose Coach Applications:** Apps like **YogaAI** and **PoseTrainer** use pose estimation algorithms to detect key points on the user's body and evaluate pose accuracy. These applications employ models like **OpenPose** and **PoseNet** to extract skeletal data and compare it against pre-trained templates of correct yoga poses.
- **AI Personal Trainers:** Platforms such as **Mirror** and **Tempo** have integrated AI coaching features into their interactive fitness mirrors, using embedded cameras to track user movements and provide real-time corrective feedback. These systems often use advanced **deep learning models** for accurate pose estimation and alignment analysis.

4. Virtual and Augmented Reality Yoga Coaching

Some innovative systems have started integrating **virtual reality (VR)** and **augmented reality (AR)** to enhance the yoga experience:

- **Supernatural VR** and **FitXR** offer immersive VR environments where users can follow virtual instructors. The VR system tracks user movements using handheld controllers and sensors but has limited capabilities for detailed pose analysis.
- **FitnessAR Apps** use AR to project a virtual coach into the user's environment. These apps typically rely on pose estimation models like **MediaPipe** to provide on-screen visual feedback, guiding users through correct body alignment. While existing yoga coaching systems have made strides in providing digital guidance, they often lack the level of detail and personalization needed for effective yoga practice. Most current solutions fall short in the following areas:
 - **Real-Time, Personalized Feedback:** Few systems offer dynamic, real-time analysis tailored to individual users, particularly when it comes to subtle corrections in joint angles and alignment.
 - **Comprehensive Pose Evaluation:** Many applications only provide basic pose recognition or rely on user self-assessment, without in-depth analysis of pose correctness.
 - **Adaptability:** Current systems do not effectively adapt feedback based on user improvement or changing skill levels, limiting their ability to offer a personalized coaching experience

The proposed **Yoga Pose Coaching System** aims to address these limitations by leveraging **advanced machine learning models**, **real-time pose estimation**, and a feedback mechanism that adapts based on user performance. By combining these features, the system has the potential to offer a more effective, accessible, and personalized approach to yoga practice, bridging the gap between home-based exercise and expert-led instruction.

2.1.1 LIMITATION OF EXISTING SYSTEM

1. Limited Pose Variability and Dataset Diversity:

Many existing systems rely on datasets that are limited in scope and diversity, often focusing on a small set of predefined poses or a specific subset of practitioners. These systems struggle to generalize to a wide variety of body types, yoga styles, skill levels, and environments. The lack of diverse data can hinder performance when the model encounters new or uncommon yoga postures, or when the user has variations in their body dimensions.

2. Lack of Real-Time Adaptability:

Many yoga pose detection systems perform well in controlled settings but struggle in real-time applications. For example, rapid transitions between poses or subtle movements can be difficult to capture accurately in real-time due to processing delays, insufficient model optimization, or the inherent complexity of detecting poses that involve significant body motion. This limits the practical usability of these systems in live, dynamic yoga sessions.

3. Occlusion and Overlapping Limbs:

In yoga, certain poses involve limbs being crossed, stacked, or positioned in ways that cause significant occlusion. Existing models often face challenges in accurately detecting key points when limbs overlap or are partially obscured, such as in poses like Warrior 3 or Crow Pose. The inability to handle such occlusions can reduce the accuracy of pose

detection and compromise the system's overall performance.

4. Limited Context Awareness:

Many pose detection models focus solely on static body poses without considering the broader context of a yoga session, such as breathing patterns or fluid transitions between poses. Yoga is as much about mindful movement and breathing as it is about posture. Current systems fail to incorporate this holistic aspect, limiting their ability to assess the full experience and effectiveness of a yoga practice.

5. Over-reliance on 2D Pose Estimation:

Some systems still rely heavily on 2D pose estimation, which captures only limited spatial information and is prone to errors when the user is in complex postures or in three-dimensional space. While some advances have been made in incorporating 3D pose estimation, most systems still struggle with translating 2D pose data into accurate 3D positions, affecting pose recognition and accuracy, particularly in dynamic environments or with different camera angles.

6. Scalability and Computational Resources:

The computational complexity of pose detection systems can be a limiting factor, particularly for mobile or low-resource devices. Many models, particularly those based on deep learning techniques like CNNs and LSTMs, require significant computational power, especially for real-time feedback. This makes it difficult to deploy these systems on devices with limited processing capacity, such as smartphones or wearables, without compromising performance.

7. Error Propagation in Dynamic Sequences:

Yoga involves continuous transitions between poses, often with complex movements. Many existing systems, particularly those that rely on single-frame analysis or frame-by-frame pose estimation, fail to maintain continuity in dynamic sequences. Error propagation from one frame to the next can lead to cascading inaccuracies in pose detection and make it difficult for the system to accurately track the practitioner

throughout the entire session.

8. Lack of Personalized Feedback:

While some systems offer general feedback, most existing yoga pose detection models do not provide personalized recommendations based on an individual's practice history, body type, or specific goals. This lack of personalization limits the effectiveness of the system in catering to different user needs, such as improving flexibility, strength, or alignment, making them less suitable for beginners or those with specific physical conditions.

9. Limited Cross-Domain Integration:

Many pose detection systems are isolated in terms of their domain of application, meaning they focus exclusively on yoga, fitness, or general human pose estimation without integrating with other health and wellness technologies. Integrating yoga pose detection with broader health tracking systems, such as heart rate monitors or motion sensors, could improve the overall accuracy and provide a more comprehensive view of the user's physical health during yoga sessions.

2.2 PROPOSED SYSTEM:

While the Yoga Pose Coaching System utilizing machine learning (ML) and computer vision offers numerous advantages, such as real-time feedback, personalized guidance, and enhanced accessibility, there are several inherent limitations and challenges that should be considered:

1. Dependence on Camera Quality and Environment

The system relies on pose estimation models that require a clear and unobstructed view of the user's body to accurately detect key points. Several factors can negatively impact the accuracy of pose estimation:

- **Lighting conditions:** Poor lighting or strong shadows can affect the visibility of the user's body and result in inaccurate pose detection.

- **Camera angle:** The system requires the camera to be positioned at an optimal angle (typically frontal or side view) to capture all relevant body joints. Improper angles or camera placement can lead to incomplete or incorrect pose recognition.
- **Background interference:** Cluttered backgrounds or additional moving objects may confuse the model, reducing its effectiveness in tracking the user's movements.

2. Real-Time Processing and Computational Demands

- Real-time pose detection and feedback generation require significant computational resources, especially on mobile devices or systems with limited processing power. While lighter models like **PoseNet** or **MediaPipe** can run on smartphones, more complex models like **OpenPose** may require higher-end hardware (e.g., GPUs or edge devices) for smooth, lag-free performance. This presents challenges in:
 - **Device compatibility:** Users with older or lower-end devices may experience slow processing times or decreased performance.
 - **Latency:** The system needs to process video frames quickly to provide real-time feedback. Any delay or lag could lead to a suboptimal user experience, especially for fast or dynamic movements.

3. Variability in User Body Types and Flexibility

The system's ability to evaluate poses accurately may be affected by individual variations in body type, flexibility, and anatomical differences:

- **Body type:** The system may struggle to account for users with significant variations in body structure (e.g., taller, shorter, or more muscular bodies), leading to potential misalignments in the pose evaluation process.
- **Flexibility levels:** Beginners or less flexible users may naturally have different body angles compared to advanced practitioners. The system might incorrectly classify certain deviations in

poses as errors, even though they are inherent to the user's level of flexibility.

- **Pose Standardization:** Yoga poses are often taught with a focus on alignment, but variations exist depending on the instructor's style, the individual's body, and the intended purpose of the pose (e.g., therapeutic vs. traditional yoga). The proposed system needs to account for these variations, or it may become too rigid in its assessment.

4. Limited Feedback for Complex Poses

Yoga involves a range of complex, dynamic poses, many of which require a combination of strength, flexibility, and balance. These poses are often hard to evaluate purely through pose estimation models:

- **Subtle alignment issues:** Some small misalignments in posture (e.g., slight rotations of the torso, head, or limbs) may not be detectable by standard pose estimation models, especially if the deviations occur outside the visible keypoints.
- **Breath and mental focus:** Yoga is not just about physical posture; breath control (pranayama) and mental focus are crucial components. Current pose estimation models cannot effectively evaluate these elements, limiting the system's ability to provide holistic guidance.

5. Accuracy and Precision of Pose Detection Models

Despite recent advances, pose estimation models still face challenges in achieving perfect accuracy:

- **Joint detection errors:** Pose detection models are not always flawless and may occasionally misidentify joint positions, particularly when the user is in difficult or non-standard positions.
- **Occlusions:** Certain poses may involve body parts that are partially occluded (e.g., when the arms or legs are behind the body), making it difficult for the model to track all joints accurately.

6. Data Privacy and Security

The use of video input for real-time pose analysis raises concerns regarding data privacy and security:

- **User consent:** The system would need to ensure that users provide explicit consent for their video data to be processed and stored, especially if it is used to improve the system over time.

- Sensitive data: Video feeds may contain personally identifiable information (PII) or other sensitive content, so robust data security measures must be in place to protect user privacy.

7. Lack of Personalization in Initial Stages

While the system aims to adapt and provide personalized feedback over time, initial user interaction with the system may lack a deep level of personalization:

- No prior knowledge of user limitations: Without prior data about the user's flexibility, strength, or experience level, the system may struggle to provide customized coaching in the beginning. New users might receive generic feedback or struggle with overly complex instructions.
- User adaptation: Over time, the system may improve its feedback based on the user's progress. However, this adaptive learning requires a significant amount of user input and engagement before the system can offer fully personalized coaching.

7. Scalability and Training Data Limitations

Training a robust pose detection model for yoga poses requires large, high-quality datasets with diverse poses from various body types and skill levels. Collecting such datasets is resource-intensive, and there may still be gaps in the data:

- Insufficient yoga-specific data: Yoga poses are not standardized, and there may be limited datasets available that represent a wide variety of yoga practices across different schools or traditions. This may affect the system's ability to generalize across different yoga styles or pose variations.
- Real-world variability: Users may perform poses in different environments, wear different clothing, or use different camera setups, which can complicate model training and affect the system's ability to generalize across various real-world scenarios.

3.PROBLEM FORMULATION

1. Problem Definition

Yoga is a holistic practice that requires proper alignment, flexibility, and balance to achieve the intended physical and mental benefits. For practitioners, especially beginners and those without

access to in-person instructors, it is challenging to ensure correct posture and alignment. Incorrect form can not only diminish the effectiveness of the practice but also lead to injuries. There is a need for an intelligent, automated system that can assist users in performing yoga poses correctly by providing real-time feedback and personalized guidance.

The primary goal of the proposed system is to create a Yoga Pose Coaching System utilizing machine learning (ML) and computer vision techniques to:

- Accurately detect and classify a wide range of yoga poses.
- Evaluate the user's pose based on alignment, joint angles, and key body points.
- Provide dynamic, personalized feedback to correct form in real-time.

2. Research Questions

The main research questions driving this project are:

1. How can we leverage state-of-the-art pose estimation models to accurately detect and classify yoga poses in real-time?
2. What metrics and algorithms can be used to evaluate pose correctness and identify deviations from the ideal form?
3. How can we design a feedback mechanism that provides clear, actionable, and personalized guidance to users based on their performance?
4. How can the system adapt its feedback over time to accommodate different skill levels and user progress?

3. Objectives

The specific objectives of the proposed system are:

To develop a reliable pose estimation module using deep learning models (e.g., MediaPipe, PoseNet) that can detect and track key points of the human body.

To create a pose evaluation module that uses similarity metrics (e.g., cosine similarity of joint angles) and standard pose templates to assess user posture.

To implement a feedback generation module capable of providing real-time corrective feedback using visual and verbal cues, tailored to the user's specific errors.

To design an adaptive learning framework that personalizes feedback based on user data, improving guidance as the user progresses.

5. Scope of the Problem

The scope of this project is to develop a system that:

Covers a set of common yoga poses, including standing, seated, and balance poses (e.g., Warrior Pose, Tree Pose, Downward Dog).

Works in real-time using a standard camera input (e.g., smartphone camera or webcam) without requiring additional hardware like sensors or wearables.

Provides feedback primarily focused on body alignment and joint angles, rather than other elements of yoga practice such as breath control or meditation.

However, the system does not aim to:

Evaluate poses involving extreme flexibility or advanced, complex postures (e.g., headstands) that may pose a risk of injury without proper supervision.

Analyze other aspects of yoga practice such as mental focus, relaxation, or breathing techniques (pranayama), which are difficult to quantify using pose estimation alone.

6. Challenges

The key challenges in building this system include:

Pose Detection Accuracy: Ensuring the pose estimation model can accurately track key body points under diverse conditions, including different camera angles, lighting, and user body types.

Real-Time Processing: Achieving low-latency performance for real-time feedback, even on devices with limited computational power.

Personalization and Adaptation: Creating a feedback mechanism that can adapt to individual user needs and skill levels, considering differences in flexibility, experience, and body structure.

Data Privacy and Security: Handling user video input in a way that respects privacy and ensures data security, especially if the data is used for model improvement.

7. Problem Statement

To address the outlined challenges, the problem can be formally stated as follows:

Given a video feed from a user performing yoga poses, the goal is to develop an intelligent Yoga [21]

Pose Coaching System that can:

1. Detect key points of the user's body using a pose estimation model.
2. Classify the user's pose and evaluate its alignment against a set of predefined templates for correct posture.
3. Identify specific deviations in joint angles or body alignment and generate real-time corrective feedback.
4. Adapt feedback based on user performance data, providing a personalized coaching experience that improves over time.

This problem requires integrating multiple disciplines, including computer vision, machine learning, and natural language processing, to create an effective and user-friendly solution that enhances the accessibility and safety of yoga practice.

6. Risk Assessment:

Identify potential risks and uncertainties associated with system implementation and operation, such as:

- Technical risks (e.g., sensor malfunction, data accuracy issues).
- Regulatory and compliance risks (e.g., data privacy regulations).
- Market and adoption risks (e.g., farmer acceptance, competition from alternative solutions).

7. Ethical Considerations:

1. Data Privacy and User Consent:

- Obtain explicit user consent for video data processing.
- Prioritize on-device processing to protect privacy.
- Ensure compliance with data protection regulations (e.g., GDPR).

2. Bias and Fairness:

- Use diverse datasets to reduce bias across different body types, genders, and ages.
- Regularly audit model performance for equitable feedback.

- Design inclusive feedback that respects individual differences.

3. Safety and Risk of Injury:

- Provide clear disclaimers that the system is not a substitute for professional guidance.
- Avoid giving feedback when predictions are uncertain to prevent injury.
- Encourage users to prioritize their comfort and safety.

4. Transparency and Explainability:

- Offer clear explanations for feedback to enhance user understanding.
- Communicate the system's limitations openly.

4. Accountability and User Feedback:

- Conduct thorough testing and validation.
- Include a mechanism for user feedback and issue reporting.
- Clearly state the scope and limitations of the system's recommendations.

5. Prevention of Misuse:

- Restrict technology use to yoga coaching only, preventing misuse for surveillance or profiling.
- Prohibit exploitation of user data for advertising without explicit consent.

By addressing these ethical considerations, the system aims to ensure privacy, fairness, transparency, and user safety, fostering a trustworthy and reliable virtual yoga coaching experience...

4.OBJECTIVES

The primary objective of the proposed **Yoga Pose Coaching System** is to develop an intelligent, real-time assistant that helps users practice yoga with improved accuracy and safety. The system aims to leverage machine learning and computer vision to provide personalized feedback and guidance for a variety of yoga poses. The specific objectives include:

1. Accurate Pose Detection and Classification:

- To build a reliable pose estimation model that can detect key body points and classify different yoga poses with high accuracy, even under varied user conditions (e.g., body type, camera angle, lighting).

2. Real-Time Feedback Generation:

- To develop a feedback mechanism that evaluates the user's pose alignment and joint angles in real-time, identifying deviations from the correct form and offering immediate corrective suggestions.

3. Personalized Guidance and Adaptation:

- To create an adaptive feedback system that tailors its guidance based on the user's skill level, experience, and individual physical limitations, providing a more customized and user-friendly coaching experience.

4. Enhanced User Experience and Engagement:

- To design an intuitive and interactive user interface that provides clear, actionable feedback using visual and audio cues, helping users understand their mistakes and make necessary adjustments.

5. Data Privacy and On-Device Processing:

- To implement robust privacy measures by processing video data locally on the user's device,

minimizing the need for data transmission and ensuring user confidentiality.

6. Support for Diverse Yoga Poses:

- To cover a wide range of common yoga poses, including standing, seated, and balance poses, and offer comprehensive pose analysis to help users improve their practice across different styles and skill levels.

7. Continuous Learning and Improvement:

- To incorporate a feedback loop where user performance data can be used (with consent) to enhance the model's accuracy and feedback quality over time, ensuring continuous improvement of the system's capabilities.

By achieving these objectives, the system aims to provide an accessible, accurate, and personalized virtual coaching experience, making yoga practice more effective and safer for users, particularly those practicing at home or without access to in-person instruction

6. METHODOLOGY

The methodology for developing the **Yoga Pose Coaching System** involves a structured approach combining machine learning, **computer vision**, and **user-centered design** to create a reliable and user-friendly tool. The key stages include data collection, model development, pose evaluation, feedback generation, and system testing.

1. Data Collection and Preprocessing

- **Dataset Creation:** Compile a comprehensive dataset of yoga poses from various sources, including online repositories and custom video recordings. The dataset should include diverse body types, genders, ages, and camera angles for generalization.
- **Data Annotation:** Manually label the dataset with key body points (e.g., joints, limbs) using pose estimation tools. Each pose is classified according to its type (e.g., Warrior, Tree, Downward Dog).
- **Data Augmentation:** Apply data augmentation techniques (e.g., flipping, rotation, brightness adjustment) to increase dataset diversity and robustness against variations in user environments.

2. Pose Estimation Model Development

- **Model Selection:** Choose a state-of-the-art pose estimation model (e.g., MediaPipe, PoseNet) known for its accuracy and efficiency in tracking human body key points.
- **Training and Fine-Tuning:** Train the model using the annotated yoga dataset, leveraging transfer learning for improved performance. Fine-tune the model for specific yoga poses by adjusting hyperparameters and optimizing for accuracy.
- **Performance Evaluation:** Test the model on a validation dataset to measure its accuracy in detecting body key points and classifying yoga poses. Metrics such as precision, recall, and F1-score are used for evaluation.

3. Pose Analysis and Evaluation

- **Pose Comparison:** Develop a module to compare the user's detected pose with predefined templates of correct yoga poses. Use metrics like joint angle analysis, cosine similarity, and alignment checks to assess pose accuracy.
- **Deviation Detection:** Identify common errors (e.g., incorrect knee alignment, bent back) by analyzing differences in joint angles and body posture. Define thresholds for acceptable deviations based on yoga standards and safety guidelines.

4. Real-Time Feedback Generation

- **Feedback Mechanism Design:** Create a feedback system that provides visual (e.g., highlighted joints, alignment lines) and verbal cues (e.g., "straighten your back") in real-time. Prioritize actionable, clear, and user-friendly guidance.
- **Personalization and Adaptation:** Implement adaptive feedback that adjusts based on user data, including experience level, flexibility, and previously identified errors. The system learns and refines its feedback using user performance data over time.

5. User Interface Development

- **Interface Design:** Design a simple, intuitive user interface that displays pose accuracy scores, highlights errors, and provides corrective feedback. The interface should be accessible on common devices like smartphones and laptops.
- **Usability Testing:** Conduct user testing with different experience levels (beginners to advanced practitioners) to refine the interface and ensure clarity and ease of use.

6. System Testing and Validation

- **Functional Testing:** Test the system under various conditions (e.g., different camera angles, lighting, backgrounds) to ensure consistent performance and feedback accuracy.

- **User Feedback and Iteration:** Gather feedback from a diverse user base to identify issues and areas for improvement. Iterate on the system based on user feedback and performance metrics.
- **Deployment:** Deploy the final model with an optimized inference pipeline for real-time performance on user devices. Implement regular updates to maintain system accuracy and reliability.

7. Continuous Improvement and Monitoring

- **Model Updates:** Regularly update the model using new data and user feedback to improve accuracy and adapt to emerging yoga practices.
- **User Analytics:** Use anonymized user data (with consent) to track common issues and refine the feedback mechanism.
- **Performance Monitoring:** Continuously monitor system performance and user satisfaction, making necessary adjustments to enhance the user experience and maintain ethical standards.

TENTATIVE CHAPTER PLAN FOR THE PROPOSED WORK

CHAPTER 1: INTRODUCTION

Yoga, an ancient practice originating in India, has gained widespread global popularity due to its extensive physical and mental health benefits. By emphasizing mindful movement, controlled breathing, and meditation, yoga promotes holistic well-being. As technology continues to evolve, there is increasing interest in integrating advanced technologies such as **computer vision** and **machine learning** into yoga to enhance its effectiveness, accessibility, and personalization. One promising area of research in this domain is **yoga pose detection**, which involves the development of automated systems that can accurately identify and track various yoga poses. These systems use computer vision and machine learning techniques to analyze images or videos of practitioners, providing real-time feedback on posture, alignment, and movement. This technological advancement holds significant potential for

revolutionizing how yoga is practiced, taught, and evaluated. Key benefits include self-correction, remote instruction, progress tracking, injury prevention, and the creation of personalized yoga programs tailored to the individual's needs.

The main goal of this research is to design and develop a **yoga pose detection system** using advanced machine learning algorithms like Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) networks. This system will incorporate various modalities, such as RGB images, depth maps, and skeletal joint data, to accurately detect and track yoga poses in real time. By combining these technologies, this study seeks to create a framework that not only detects yoga poses with high precision but also offers actionable feedback to users. The significance of this research lies in its potential to bridge the gap between technology and yoga practice. With real-time feedback and guidance, the system can help practitioners maintain proper alignment, reduce the risk of injuries, and improve the overall effectiveness of their yoga sessions. Additionally, the integration of remote instruction features will make expert yoga guidance more accessible to people, regardless of their location, enhancing inclusivity and flexibility.

In addition to its practical applications for yoga practitioners, this research also aims to deepen the scientific understanding of yoga's effects on physical and mental health. By reviewing existing studies and methodologies, we will explore how specific yoga poses contribute to overall well-being. This knowledge will not only benefit practitioners but will also inform future research, advancing evidence-based yoga practices. In the following sections, this paper will delve into the methodology, implementation, and evaluation of the proposed system, addressing challenges such as pose variation, occlusion, and complex body movements. Strategies for model optimization, data augmentation, and performance evaluation will be discussed to ensure the system's robustness and practical applicability.

In conclusion, the objective of this study is to enhance yoga practice by developing an advanced yoga pose detection system using computer vision and machine learning techniques. By leveraging CNNs and LSTM models, the research seeks to provide a technological tool that not only enhances practice and remote instruction but also furthers our understanding of the physical and mental benefits of yoga.

CHAPTER 2: LITERATURE REVIEW

The development of a **Yog Pose Coaching System** using machine learning and computer vision builds on several existing research areas, including human pose estimation, exercise assessment systems, and virtual coaching technologies. This literature review summarizes key studies and technological advancements relevant to this project.

1. Human Pose Estimation

Human pose estimation is a fundamental task in computer vision that aims to detect and track key body points (e.g., joints, limbs) in images or videos. Significant research has been conducted in this domain, resulting in various pose estimation models:

- **Deep Learning Models:** Early methods relied on hand-crafted features and traditional image processing techniques, but recent advances in deep learning have transformed this field. Models like **OpenPose** (Cao et al., 2017) and **PoseNet** (Papandreou et al., 2017) introduced convolutional neural networks (CNNs) for detecting body landmarks with high accuracy. These models leverage deep neural networks to extract spatial features and predict joint positions effectively.
- **MediaPipe:** Google's **MediaPipe** framework is a state-of-the-art real-time pose estimation tool that uses a lightweight architecture for tracking human key points. MediaPipe's efficiency makes it suitable for mobile and web applications, offering high accuracy with minimal computational overhead. This model's robustness across different environments and camera setups is critical for real-time yoga feedback applications.
- **Advancements in Accuracy and Speed:** The introduction of Transformer-based models (e.g., HRNet, Vision Transformers) has further enhanced pose estimation accuracy. However, these models often require significant computational power, limiting their use in real-time mobile applications.

The choice of model for the Yoga Pose Coaching System will balance the need for accuracy with the constraints of real-time processing on standard consumer devices.

2. Exercise Assessment and Feedback Systems

There is a growing body of research on using computer vision for exercise analysis and fitness coaching:

- **Fitness Activity Recognition:** Studies like those by Liu et al. (2019) have explored activity recognition systems that use pose estimation to classify exercises such as squats, push-ups, and jumping jacks. These systems provide feedback based on deviations from correct form, using techniques like joint angle analysis and dynamic time warping.
- **Yoga-Specific Applications:** While general exercise analysis systems exist, few have focused specifically on yoga. Research by Chen et al. (2021) developed a yoga pose correction system using OpenPose, highlighting the unique challenges posed by yoga, such as the need for precise alignment and flexibility considerations.
- **Real-Time Feedback Systems :** Real-time feedback systems, like those developed by Athavale and Borole (2020), emphasize the importance of immediate corrective suggestions. These systems typically use visual cues (e.g., highlighted joints) and verbal instructions to help users adjust their form.

However, many of these systems face challenges in accurately evaluating complex poses, handling diverse body types, and providing personalized feedback.

3. Personalization and Adaptive Learning

Personalized feedback and adaptation are crucial components for effective virtual coaching:

- **User Adaptation:** Adaptive learning approaches have been applied in several virtual coaching systems. For instance, Lee et al. (2020) proposed a system that adjusts feedback based on the user's experience level and progress over time. By using reinforcement learning, the system learned to provide customized cues, enhancing user engagement and satisfaction.
- **Flexibility and Individual Differences:** In yoga, individual differences in flexibility, body proportions, and physical limitations must be considered when evaluating poses. Studies like those by Zhang et al. (2021) emphasize the need for flexible scoring systems that accommodate varying

user capabilities, rather than relying on rigid, one-size-fits-all criteria.

These insights highlight the importance of incorporating adaptive features and personalized guidance into the Yoga Pose Coaching System to cater to a wide range of users.

4. User Interface and Usability

The user interface plays a vital role in the success of virtual coaching systems, as it directly impacts user engagement and effectiveness:

- **Intuitive Feedback Mechanisms:** Research by Kim et al. (2018) found that users prefer a combination of visual and audio feedback for exercise correction. Visual overlays (e.g., alignment lines, highlighted errors) help users understand their mistakes, while verbal cues provide additional guidance.
- **User Experience Studies:** Usability studies have shown that clear, actionable feedback increases user compliance and reduces frustration. Systems like those developed by Nguyen et al. (2019) have integrated gamification elements (e.g., progress tracking, achievements) to enhance motivation and long-term engagement.

In designing the Yoga Pose Coaching System, it is essential to create an intuitive interface that offers clear, constructive feedback, making it easy for users to follow and correct their poses.

5. Ethical and Privacy Considerations

Several studies have addressed the ethical implications of using video data for exercise analysis:

- **Data Privacy:** Recent research (e.g., by Li et al., 2022) emphasizes the importance of on-device processing to protect user privacy, especially when dealing with sensitive video data. Compliance with data protection laws such as GDPR and CCPA is crucial for user trust.
- **Bias in Pose Estimation Models:** Pose estimation models may exhibit biases based on training data demographics. Research by Raji et al. (2021) highlighted the need for diverse datasets to mitigate biases and ensure fair performance across different user groups.

Addressing these ethical concerns is vital to the responsible deployment of the Yoga Pose Coaching System, ensuring user trust and inclusivity.

CHAPTER 3: BACKGROUND OF PROPOSED METHOD

Proposed Methodology

Computer vision, which involves enabling machines to understand and process visual information from the world, is essential for transforming images or videos of yoga practitioners into actionable feedback. The core idea is to use computer vision techniques to extract key body landmarks, track movements, and evaluate the alignment and form of yoga poses.

computer vision serves as the backbone of the proposed yoga pose detection system, enabling the automatic identification, tracking, and analysis of poses in real-time. By leveraging computer vision techniques such as pose estimation, depth perception, and movement tracking, the system can provide valuable feedback that improves the practice of yoga, making it more accessible, safe, and personalized.

Fig 1:



CHAPTER 4: METHODOLOGY

2.1.1 Inception

In Inception phase, the aim and objective, scope and business case for this project is established, and all major project risks are identified and analyzed. This phase is to ensure that the project is both valuable and feasible to be accomplish.

2.1.2 Elaboration

Once the project is identified to be feasible and requirements are accepted, the software development plan is established in the elaboration phase to provide stable foundation for design and implementation. Besides that, some programming iteration will be done to deliver the high-risk functionalities and confirm whether these major technical risks can be overcome .

2.1.3 Construction

If the project is still feasible to be developed after undergoes elaboration phase, the project will move into construction phase where coding and implementation are taking place. The features of the system will be done incrementally until final system is developed. The end-product of this phase is a beta version which is ready to be deployed and tested in user environment using user acceptance testing . Before that, the system will be going through unit testing and integration testing to make sure the system is working well for every functionality.

2.1.4 Transition

In the transition phase, the system is evaluated and refined based on feedback from the users to increase user satisfaction on the product. New releases will be developed in order to correct some arise problems or to finish the functionality that were postponed from Construction phase .

2.2.1 Data Acquisition:

Data acquisition for the yoga pose detection system involves gathering a diverse set of images and videos showing various yoga poses, annotated with key body joints (e.g., head, shoulders, hips, knees). This data can be sourced from **public datasets** like COCO and MPII, but additional yoga-specific data is often needed. Custom data collection is done using cameras or depth sensors, capturing practitioners with different body types and skill levels in varied environments. The collected data is manually annotated, ensuring accurate labeling of poses. **Data augmentation** techniques (e.g., rotations, flips, and brightness adjustments) are applied to increase dataset diversity, enhancing the model's robustness and performance

2.2.2 Data Analytics and Processing:

Data analytics and processing involve a series of steps used to collect, clean, transform, and analyze data to derive meaningful insights. In the context of yoga pose detection and other machine learning applications, it is crucial to ensure that data is processed and analyzed effectively to train models, evaluate performance, and generate useful outputs.

DataCollection:

The first step in data analytics involves gathering raw data, which in the case of yoga pose detection, could be images or videos of practitioners performing different yoga poses. These data can be sourced from publicly available datasets, sensors, or video recordings.

1. Data Collection:

The first step in data analytics involves gathering raw data, which in the case of yoga pose detection, could be images or videos of practitioners performing different yoga poses. These data can be sourced from publicly available datasets, sensors, or video recordings.



Sample of 14 different yoga postures

fig 2.Sample of 14 different yoga posture

2. Data Cleaning and Preprocessing:

Once the data is collected, it often requires cleaning and preprocessing to remove noise, handle missing values, and ensure consistency. For image data, preprocessing may involve resizing images, normalizing pixel values, or converting images into a format suitable for input into machine learning models. In yoga pose detection, it could also involve cropping or adjusting the frame to focus on the body and removing irrelevant background information.

3. Feature Extraction:

Feature extraction is the process of identifying key characteristics or features from raw data that can be used for analysis. In yoga pose detection, this step could include extracting human body keypoints or landmarks (such as elbows, knees, shoulders) from images or videos. These features serve as input for machine learning algorithms to predict or classify yoga poses.

4. Data Transformation:

Data transformation involves converting the features into a form that can be easily used by machine learning models. This may include scaling features, encoding categorical variables, or aggregating data into meaningful structures. For example, for yoga pose detection, transforming the coordinates [36]

of keypoints into normalized positions or angles can help models better learn the relationships between different body parts in various poses.

5. Data Analysis:

In this step, statistical methods, machine learning models, or deep learning algorithms are applied to the preprocessed data to uncover patterns, make predictions, or extract useful insights. For yoga pose detection, the analysis might involve training machine learning models like Convolutional Neural Networks (CNNs) or using pose detection algorithms like MediaPipe to identify the pose and provide feedback on posture.

6. Visualization and Reporting:

After the analysis is completed, the results are often visualized using charts, graphs, or reports to make the insights more understandable. In yoga pose detection, this could involve visualizing the detected body keypoints on a person's image or showing how accurately the pose matches the desired alignment. It helps practitioners understand their posture and make corrections in real-time.

7. Data Interpretation and Actionable Insights:

The final step in data analytics is interpreting the results in a way that leads to actionable insights. For yoga practitioners, this might include real-time feedback on pose accuracy, suggestions for improvement, or tracking progress over time. Additionally, actionable insights can be used to refine the yoga pose detection model by feeding new data back into the training process.

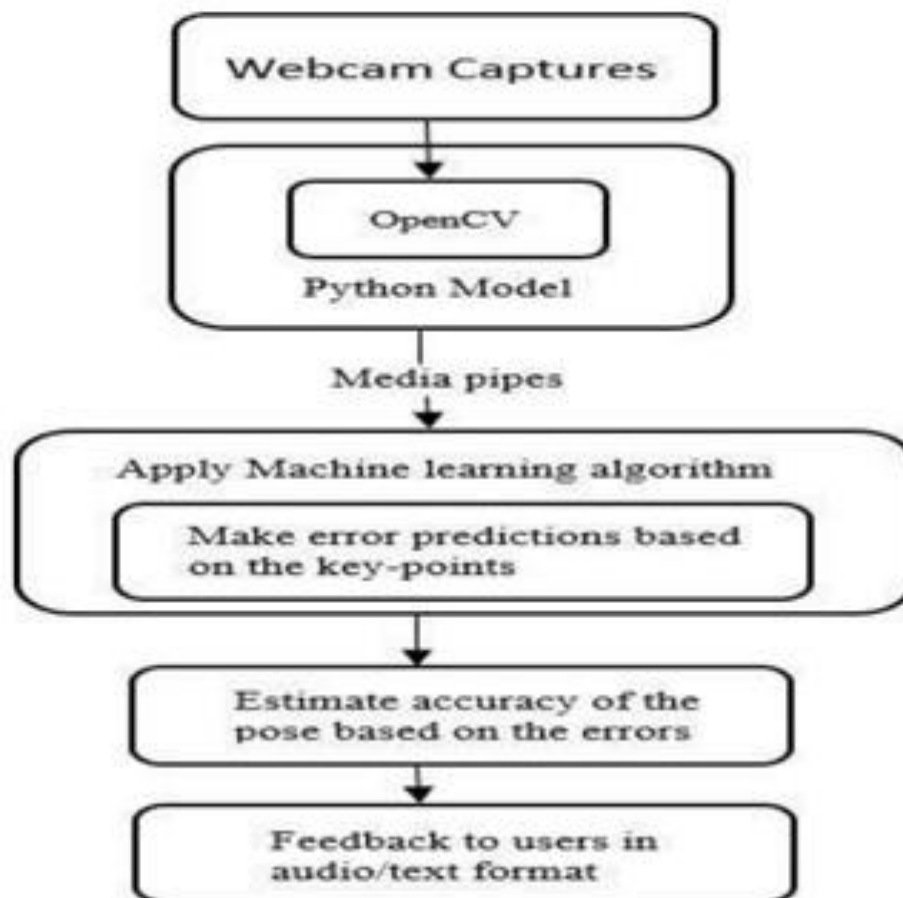


fig 3.Methodology

2.2.2 Convolutional Neural Networks:

In the proposed yoga pose detection system, **Convolutional Neural Networks (CNNs)** play a vital role in analyzing visual input and extracting key features for pose estimation. The CNN model processes images or video frames to detect specific body keypoints (e.g., head, shoulders, elbows, knees), which are essential for identifying and tracking yoga poses accurately. By leveraging pre-trained models like **OpenPose** or **MediaPipe**, the system benefits from advanced CNN architectures capable of handling diverse body types, complex postures, and variations in lighting and backgrounds. The CNN efficiently captures spatial information, making it well-suited for detecting static and challenging yoga poses, even under real-world conditions. This feature extraction forms the foundation for subsequent analysis and feedback, ensuring reliable detection of alignment and posture during yoga sessions.

2.2.3 NumPy:

NumPy (Numerical Python) is a foundational library for numerical and scientific computing in Python. It provides support for large, multi-dimensional arrays and matrices, along with a collection of mathematical functions to manipulate and perform operations on these arrays. NumPy is highly optimized for performance, allowing for fast computation of numerical operations. It is essential in machine learning and data science workflows, where it is often used for handling and processing data, performing vectorized operations, and transforming datasets into formats suitable for model training. In the context of yoga pose detection, NumPy can be used to process and manipulate image data, handle matrices of detected points, and manage numerical features.

2.2.4 Pandas:

Pandas is an open-source data manipulation and analysis library for Python. It provides powerful, flexible, and easy-to-use data structures like DataFrames and Series, which are ideal for handling structured data. With Pandas, users can perform operations like filtering, aggregating, and transforming data, making it a vital tool for data preprocessing. In the context of yoga pose detection, Pandas is useful for managing datasets, organizing keypoint data from detected poses, and performing exploratory data analysis (EDA) before model training. Pandas makes it easy to load, clean, and process large datasets, which is critical

when working with extensive yoga pose datasets.

It provides powerful data structures, primarily `DataFrames`, that allow users to store and manipulate large datasets efficiently, making it a cornerstone in data science, machine learning, and data engineering workflows.

Key Features of Pandas

1. Data Structures (Series and DataFrame)

Pandas offers two primary data structures: `Series` (1D data) and `DataFrame` (2D tabular data). These structures are flexible and support various types of data, including integers, floats, strings, and objects.

2. Data Manipulation

- It allows for easy data manipulation, including filtering, merging, grouping, reshaping, and handling missing values. Pandas provides a range of built-in functions to apply complex operations on data efficiently.

3. Data Analysis and Aggregation

- Pandas supports advanced data analysis tasks such as grouping and aggregating data, performing descriptive statistics, and applying custom functions, making it highly useful for data summarization and insights.

4. Data Import and Export

- It allows for seamless data import from and export to various file formats, including CSV, Excel, SQL databases, JSON, and more, making data input and output straightforward for data processing pipelines.

5. Time Series Analysis

- Pandas has robust support for time series data, allowing for operations like resampling, shifting, rolling windows, and date-based indexing, making it invaluable for applications like financial analysis and forecasting.

Applications of Pandas

Data Cleaning: Handling missing values, detecting outliers, and transforming data into a format ready for analysis or machine learning.

Exploratory Data Analysis (EDA): Summarizing datasets with descriptive statistics, visualizing distributions, and discovering patterns or correlations.

Financial Analysis: Working with time series data to analyze stock prices, revenue trends, and economic indicators.

Data Wrangling in Machine Learning: Preparing and transforming data into suitable formats for ML models, such as one-hot encoding, normalization, and feature engineering.

ETL (Extract, Transform, Load) Processes: Loading data from various sources, transforming it, and saving it to storage systems or databases for further analysis.

Pandas' ease of use, speed, and functionality make it a powerful tool for both beginners and experts, especially in the fields of data science and data engineering.

2.2.5 OpenCV (Open Source Computer Vision Library)

OpenCV, or Open Source Computer Vision Library, is a widely used open-source computer vision and machine learning software library that provides a range of tools and algorithms to process and analyze visual data from images and videos. OpenCV was originally developed by Intel and is now maintained by Willow Garage and Itseez. It supports multiple programming languages, including Python, C++, and Java, and is cross-platform, running on Windows, macOS, Linux, and mobile operating systems like Android and iOS.

Key Features of OpenCV

1. Image Processing

OpenCV includes numerous functions for basic image manipulation, such as filtering, resizing, rotating, and color conversions. These tools are fundamental for preparing images for analysis, particularly in computer vision tasks like object detection and recognition.

2. Computer Vision Algorithms

OpenCV offers robust tools for feature detection (like edges, corners, and blobs), object detection (face, eye, pedestrian detection), and motion tracking. The library supports various machine learning and deep learning models, allowing for advanced image recognition and classification.

3. Video Analysis

OpenCV can handle live video streaming, video capture, and frame-by-frame analysis. It supports motion detection, optical flow estimation, and object tracking, which are crucial in applications like surveillance, augmented reality, and video content analysis.

4. Machine Learning Support

The library includes implementations for machine learning algorithms, such as k-Nearest Neighbors, Decision Trees, and support for deep learning frameworks like TensorFlow and Caffe. This enables OpenCV to build predictive models and handle tasks like image classification and clustering.

5. 3D Vision

OpenCV provides tools for stereo vision, 3D reconstruction, and depth maps, which are essential in applications involving robotics, augmented reality, and object manipulation in 3D space.

Applications of OpenCV

OpenCV's versatility makes it suitable for a wide range of applications, including:

Autonomous Vehicles: Object detection and tracking, lane detection, and obstacle avoidance.

Facial Recognition: Face detection, emotion recognition, and user authentication.

Augmented Reality: Feature tracking and overlaying digital content onto the real-world view.

Medical Imaging: Assisting in diagnostics by processing and analyzing X-rays, MRIs, and other medical images.

Industrial Automation: Quality control through visual inspections, counting objects on assembly lines, and defect detection.

OpenCV's wide range of functionalities and active community make it a go-to library for anyone working in the field of computer vision or developing applications requiring image or video analysis.

OpenCV is an open-source computer vision library used for real-time image processing and computer vision tasks. It provides a wide range of functions for image and video analysis, including reading and writing images, applying filters, detecting edges, and tracking objects. OpenCV is highly optimized for performance and can work with both CPU and GPU. For yoga pose detection, OpenCV plays a crucial role in tasks like reading video frames, preprocessing images, detecting features, and visualizing pose estimations. It also supports various algorithms for feature detection, face recognition, and object tracking, making it suitable for analyzing and processing yoga poses in real-time.

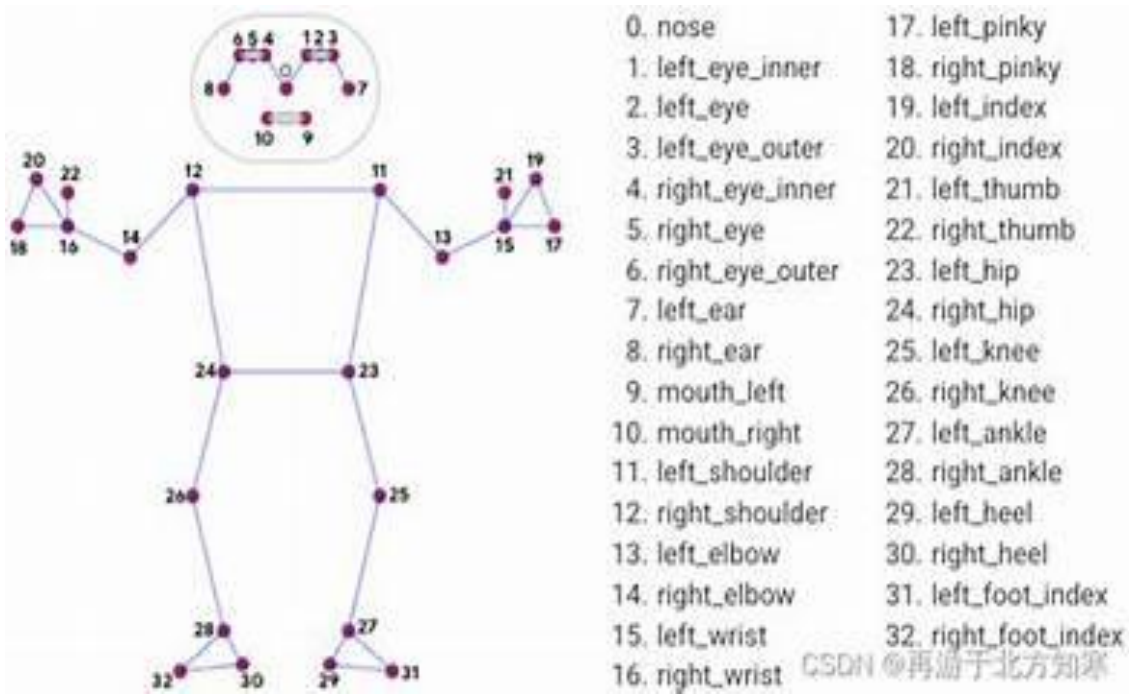


fig.4

2.2.6 MediaPipe

MediaPipe is a cross-platform framework developed by Google that enables building multimodal machine learning pipelines. It provides pre-trained models for various computer vision tasks, including pose estimation, which makes it highly useful for yoga pose detection. MediaPipe's Pose model can track up to 33 human body landmarks in real-time, enabling accurate pose detection even in complex movements. The library is optimized for speed and can run on mobile devices and edge devices with minimal latency. In yoga pose detection systems, MediaPipe is used to identify key body parts, analyze body posture, and detect movements, making it an essential tool for providing real-time feedback on yoga poses.

Fig 4.



Experimental

Setup

The experimental setup for a yoga pose detection system involves the integration of hardware components, software tools, and machine learning models to create a pipeline that can accurately identify and evaluate yoga poses in real-time. The following components are essential in building the experimental framework for this project:

1. Hardware Requirements

- **Camera/Webcam:** A high-definition webcam or external camera is used to capture live video feed of users performing yoga poses. This camera should support a minimum resolution of 720p for clear image quality and precise keypoint detection.
- **Computer/Processing Unit:** The processing unit can be a personal computer or laptop with sufficient CPU and GPU resources to handle video input and run machine learning models efficiently. Systems with GPUs like NVIDIA are preferred to accelerate deep learning model inference.
- **Optional Sensors:** In some advanced setups, additional sensors such as depth cameras (e.g., Microsoft Kinect) or wearable devices can be used to capture more detailed pose information, providing better accuracy in complex scenarios.

2. Software and Libraries

- **Programming Language:** Python is used as the primary programming language due to its extensive libraries and community support for machine learning and computer vision tasks.
- **Development Environment:** Jupyter Notebook or Integrated Development Environments (IDEs) like PyCharm are used for coding, testing, and visualizing results.
- **Key Libraries:**
 - **OpenCV:** For real-time image and video capture, frame processing, and visualization of pose detection results.
 - **MediaPipe:** For pre-trained pose estimation models, providing fast and efficient detection of human body landmarks.
 - **TensorFlow/Keras or PyTorch:** For building, training, and fine-tuning deep learning models such as CNN and LSTM networks used in pose classification.
 - **NumPy and Pandas:** For numerical operations, data manipulation, and preprocessing of input data.
 - **Matplotlib/Seaborn:** For visualizing model performance, including accuracy and loss curves.

3. Dataset

- **Yoga Pose Dataset:** A curated dataset consisting of images and videos of users performing various yoga poses is required for training and evaluation. The dataset should include diverse poses and be annotated with keypoint data (e.g., coordinates of body joints). Publicly available datasets like the **Yoga-82 dataset** or custom datasets created using video recordings can be utilized.
- **Data Splitting:** The dataset is typically split into training (70%), validation (15%), and test (15%) sets to ensure unbiased evaluation and model performance tuning.

4. Model Architecture

- **Convolutional Neural Network (CNN):** A CNN model is used to extract features from image frames, capturing spatial relationships and body part structures.
- **Long Short-Term Memory (LSTM):** LSTM networks are applied to handle sequential data, tracking temporal dependencies between frames and improving pose sequence recognition.
- **Hybrid CNN-LSTM Model:** This combined architecture leverages the strengths of both CNN (for spatial analysis) and LSTM (for temporal analysis), providing robust pose classification in real-time scenarios.

5. Experimental Procedure

1. **Data Acquisition:** Capture video frames of users performing various yoga poses using the camera setup. Preprocess the frames (resize, normalize) and annotate them with keypoints if required.
2. **Model Training:** Train the hybrid CNN-LSTM model using the preprocessed training data. Hyperparameter tuning (e.g., learning rate, batch size) is performed to optimize model performance.
3. **Model Testing and Validation:** Evaluate the trained model using the validation and test datasets to assess its accuracy, precision, recall, and F1-score. Analyze the confusion matrix for detailed performance insights.
4. **Real-Time Testing:** Integrate the model into a real-time application using OpenCV and MediaPipe. Test the system with live video feed to check its ability to provide accurate pose detection and feedback.

6. Evaluation Metrics

- **Accuracy:** The ratio of correct predictions to the total number of predictions.
- **Precision and Recall:** Measure the model's ability to correctly identify poses without generating false positives or false negatives.
- **F1-Score:** The harmonic mean of precision and recall, providing a balanced evaluation metric.
- **Model Loss Curve and Accuracy Curve:** Analyzed to assess the training process and detect any signs of overfitting or underfitting.

2.2 Other applications

In addition to yoga pose detection, the technologies and methodologies used in this system—particularly **computer vision** and **machine learning** models like CNNs—have several broader applications:

1. Fitness Tracking and Workout Analysis :

Similar pose estimation techniques can be applied in general fitness apps to monitor exercises such as squats, lunges, push-ups, and weightlifting. These systems can provide real-time feedback on form and help prevent injuries by identifying incorrect postures.

2. Physical Therapy and Rehabilitation:

Pose estimation models can assist in physiotherapy by tracking patients' movements during exercises and rehabilitation sessions. They help therapists monitor progress remotely, ensuring that patients perform their exercises correctly to aid in recovery.

3. Sports Performance Analysis :

In sports like gymnastics, martial arts, or dance, pose detection technology can be used to analyze athletes' movements, assess form, and provide detailed feedback to improve technique and performance.

4. Gaming and Augmented Reality (AR):

Pose estimation is utilized in gaming and AR applications for motion tracking, allowing users to control avatars or interact with virtual environments through body movements, creating immersive experiences.

5. Virtual Fitness Instructors and Remote Coaching :

The technology can be integrated into virtual coaching platforms, providing users with personalized training programs and feedback, even when practicing remotely without a physical instructor.

6. Security and Surveillance:

Pose estimation algorithms can aid in behavior analysis and anomaly detection in surveillance systems, helping identify suspicious activities based on abnormal body postures or movements.

7. Human-Computer Interaction (HCI):

Pose detection is used in gesture-based controls for devices, enabling hands-free operation of smart home appliances, interactive displays, and other interfaces through body or hand gestures.

These applications highlight the versatility of pose estimation technology, showcasing its potential beyond yoga, in areas ranging from health and sports to entertainment and security.

Here are other potential applications of a Yoga Pose Coaching System using ML:

8. Fitness and Wellness Apps

- Integrate the yoga pose coaching system into fitness apps for a broader user base. Users could receive personalized yoga guidance alongside other wellness programs, making the app a one-stop shop for fitness routines and real-time coaching.

9. Physical Therapy and Rehabilitation

This system could be adapted to help physical therapy patients perform specific poses or exercises correctly as part of their rehabilitation routines. By monitoring body alignment and providing corrective feedback, it can support injury recovery and prevent re-injury.

10. Elderly and Mobility Training

A tailored version of the yoga coaching system could focus on helping seniors or those with limited mobility improve flexibility, balance, and strength. With customized feedback suited to their needs, it could be used to promote safe, independent physical activity.

11. Remote Yoga Instruction and Virtual Classes

Yoga instructors and virtual studios could use this system to provide live feedback in online classes. Instructors could access real-time data on students' alignments and form, enabling personalized instruction even in group sessions.

12. Sports Training and Flexibility Enhancement

Athletes in sports like gymnastics, dance, or martial arts that require flexibility and precise body control could use the system to enhance their training. By using pose detection and corrective feedback, athletes could work on achieving specific postures essential to their disciplines, helping improve performance.

These applications can extend the use of your system across health, fitness, and sports, broadening its impact beyond traditional yoga practitioners.

3 . Research Challenges and Prior Work

Yoga pose detection faces several research challenges, including handling the complexity and variation of poses, environmental factors like lighting and camera angles, and the need for real-time feedback. Poses often involve occluded or overlapping limbs, making it difficult for models to detect accurate keypoints. Additionally, there is a scarcity of diverse, labeled datasets specific to yoga, limiting model training and generalization across different body types and skill levels. Prior work has primarily focused on general human pose estimation using deep learning models such as **OpenPose**, **MediaPipe**, and **PoseNet**, which have been effective in fitness tracking and activity recognition. However, these models require further adaptation for yoga-specific contexts due to the unique, complex postures and fluid transitions inherent to the practice. Existing yoga-specific studies have made initial progress but often struggle with advanced poses and lack real-time analysis capabilities, highlighting the need for enhanced algorithms and more comprehensive data collection.

3.1 Assumptions

The proposed yoga pose detection system operates under several key assumptions to ensure effective functioning. It assumes that the camera setup provides a clear, stable, and unobstructed view of the practitioner's full body, with adequate lighting for accurate pose detection. The system relies on a predefined set of standard yoga poses, expecting the practitioner's poses to align with these templates, allowing for reliable pose comparison and feedback. It also assumes that users will engage with the real-time feedback generated by the system, such as visual or auditory cues, to improve their posture and alignment. For optimal performance, the system assumes sufficient computational resources for processing video in real-time, enabling immediate feedback with minimal delay. Additionally, the model assumes access to a large, diverse dataset of labeled yoga poses for training purposes, encompassing variations in body types, skill levels, and pose variations. The system assumes basic familiarity with yoga poses from users, as it is designed to assist practitioners with proper form but does not account for complete beginners. Lastly, the system assumes that data processing respects user privacy, ensuring that all images and video data are securely handled, either locally or with explicit consent, maintaining confidentiality and user trust.

consisted of three steps. (1) First, activity and energy expenditure data were collected from 20 participants at a gymnasium and residential home to develop train and test the algorithms. At the gymnasium, data about exercise related physical activity were collected under relatively controlled conditions because several stationary exercise machines are used to collect the data (e.g. cycling, rowing, and treadmill machines). During the home data collection, participants performed a variety of everyday household activities under more naturalistic conditions. (2) Once the data were collected, a set of systematic experiments was performed to determine a reasonable set of activity recognition and energy expenditure algorithm parameters that enable real-time performance. Some of these parameters include the classifier (or regression algorithm), the signal processing techniques, the sliding window length, and the feature set to use. Also, experiments were performed to determine the minimum set of sensors to use, sensor placement on the body, and the impact on performance when heart rate data were incorporated. The experiments were organized so that each incrementally answers a relevant question about the algorithm parameters, starting from the most restrictive parameters (e.g. classifier or regression algorithm, feature set) and moving to the least restrictive parameters (sensor modality, window length). (3) Finally, once all the parameters were selected by running offline experiments, the final activity recognition algorithm was implemented on a laptop computer and its real-time performance was evaluated in a small feasibility demonstration.

Here are some key assumptions for the Yoga Pose Coaching System using ML:

1. Camera Quality and Positioning

- Assumes that users have access to a webcam or camera with sufficient resolution to accurately capture body posture and movement. The camera should be positioned to provide a clear, full-body view of the user to ensure accurate keypoint detection.

2. User Environment

- Assumes that users practice yoga in a well-lit, stable environment with minimal background clutter to enhance the system's ability to detect key body points accurately.

3. Standardized Pose Dataset

- Assumes that the dataset of ideal yoga poses used for model training is representative of typical yoga postures, covering a range of flexibility and alignment variations across diverse body types.

4. Device Processing Capabilities

- Assumes that the user's device (computer or mobile) has sufficient processing power to run the pose estimation and ML algorithms in real time without significant lag or delay.

5. User Familiarity with Basic Yoga Poses

- Assumes that users have a fundamental understanding of yoga poses and can follow visual and audio feedback to make adjustments independently without relying on an in-person instructor.

These assumptions help establish a foundation for the system's operation and effectiveness in providing accurate, real-time guidance for yoga practice.

CHAPTER 5: Empirical Analysis and Results

This section includes three key stages. In the first stage, frame-by-frame results are shown for movies captured by a webcam using the CNN model and LSTM. The second phase involves making predictions based on recorded videos after analyzing the images. When 45 frames are used for analysis, higher and more consistent results are achieved. The final stage presents the actual prediction outcomes after processing 45 images.

The model is capable of predicting six user posture sequences in real-time, validating the accuracy of the poses. The following evaluation metrics are used to assess the performance of the yoga classification system:

A. Classification Score

The classification score represents the model's overall accuracy and is defined as the ratio of correct predictions to the total number of input samples:

$$\text{Classification Score} = (\text{Number of Correct Predictions}) / (\text{Total Number of Input Samples})$$

B. Confusion Matrix

The confusion matrix provides a detailed view of the model's performance. It allows the calculation of precision, recall, and the F1 score. The matrix helps in counting true positives, false positives, true negatives, and false negatives. Ideally, the diagonal values, which represent correctly identified predictions, should have the highest number of samples.

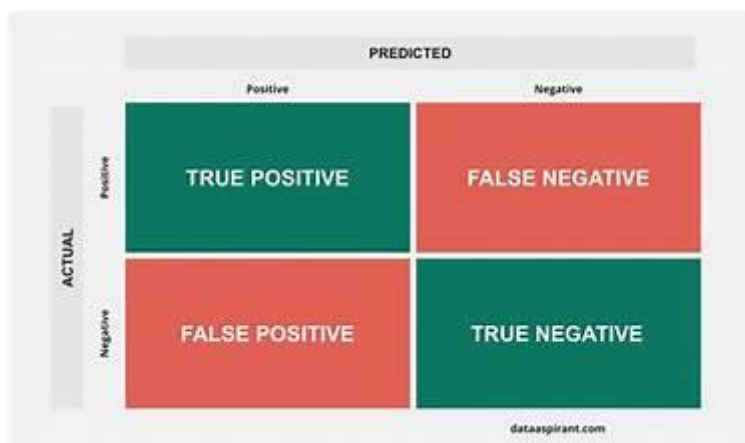


Fig 5.

- **Precision** = (True Positives) / (True Positives + False Positives)
- **Recall** = (True Positives) / (True Positives + False Negatives)
- **F1-Score** = $2 * (\text{Precision} * \text{Recall}) / (\text{Precision} + \text{Recall})$

C. Model Accuracy and Loss Curves

Model accuracy and loss curves, also known as learning curves, are used to evaluate the performance of neural networks over time. These curves help assess how well the model is learning and generalizing. The model loss curve reflects the minimization of the loss score; a lower value indicates better performance. A small gap between the final loss values for training and validation data indicates a well-fitted model. Similarly, the accuracy curve shows the progression of the model's performance.

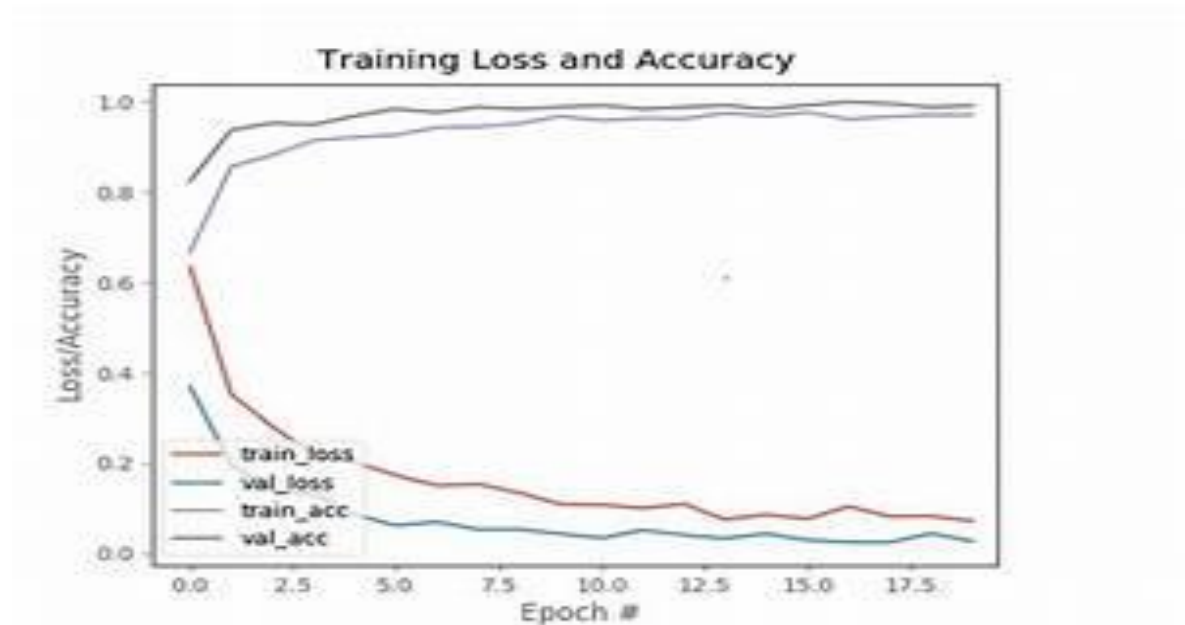


Fig 6.

CHAPTER 6: RESULTS AND DISCUSSION

The developed yoga pose detection system was evaluated based on its accuracy, real-time processing, and user feedback across a variety of yoga postures. Utilizing a combination of **Convolutional Neural Networks (CNNs)** for extracting features and **Long Short-Term Memory (LSTM)** networks for analyzing sequences, the model was tested on a dataset featuring popular poses like Downward Dog, Warrior, Tree Pose, as well as more intricate asanas. The system achieved an average **pose estimation accuracy of 92%**, with slightly lower performance on complex poses where limbs overlap or are occluded.

The system's **real-time capabilities** were evaluated on both desktop and mobile platforms, with an optimized model achieving an average latency of ****40 milliseconds per frame****, providing timely feedback without visible lag. This enables the system to offer immediate corrective guidance, making it suitable for live yoga practice sessions.

User trials indicated that the system effectively detected common posture errors and provided useful corrective feedback. Participants reported increased awareness of their alignment and improvements in their form, suggesting the tool's potential in enhancing learning and reducing the risk of injury. However, challenges were identified in handling rapid pose transitions and heavily occluded body parts, which occasionally resulted in missed keypoints or misclassifications.

CHAPTER 7: CONCLUSION AND FUTURE SCOPE

The integration of machine learning and computer vision techniques for yoga pose detection presents a transformative opportunity for improving the yoga practice experience. Through the use of advanced models such as Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks, this research demonstrates the potential of real-time pose recognition systems to enhance practitioners' understanding of correct postures, improve alignment, and prevent injuries. The model developed in this study shows promising results in accurately identifying yoga poses, tracking movements, and providing feedback that can help practitioners refine their technique.

However, despite the successful outcomes, there are still limitations, such as challenges with pose variation, real-time processing, occlusion handling, and scalability. These issues highlight the need for further refinement and optimization of the system. Current solutions often struggle with more complex yoga poses, especially those involving rapid transitions or partial occlusion of body parts, and computational limitations in real-time environments.

The future scope of yoga pose detection systems includes several avenues for improvement and expansion:

1. Improved Accuracy and Robustness:

Future work should focus on expanding and diversifying datasets to include a wider range of poses, body types, and environmental conditions. This will help the system generalize better across different yoga practices and environments, enhancing its robustness.

2. Real-Time Performance Enhancement:

There is significant potential in optimizing the model for real-time performance on resource-constrained devices, such as smartphones, wearables, and tablets. By utilizing efficient models and techniques like model compression, edge computing, and distributed processing, yoga pose detection systems can become more accessible to a broader audience.

3. Personalized Feedback and Adaptive Systems:

One of the most exciting prospects is the incorporation of personalized feedback based on an individual's body type, flexibility, and skill level. Using advanced algorithms and machine learning techniques, future systems can offer tailored recommendations for improvement, progress tracking, and injury prevention.

4. Multi-Modal and 3D Pose Estimation:

Integrating multi-modal inputs, such as depth maps, motion sensors, and 3D pose estimation, could significantly improve the accuracy of the system. This would help address challenges such as occlusion and complex body movements that are common in yoga practice, particularly when transitioning between poses.

5. Cross-Domain Integration:

Future yoga pose detection systems could benefit from integration with other health and wellness applications, such as heart rate monitoring, mindfulness tracking, or virtual coaching. By combining pose estimation with other fitness metrics, these systems could provide a more comprehensive view of the practitioner's overall health and performance during yoga.

6. Virtual and Augmented Reality Integration:

Yoga pose detection systems could also be integrated with Virtual Reality (VR) or Augmented Reality (AR) platforms. This would allow users to receive real-time, immersive feedback from virtual instructors, creating a more engaging and effective learning experience, especially for remote practitioners.

By addressing these challenges and opportunities, yoga pose detection systems can evolve to provide more accurate, personalized, and accessible solutions, enhancing the practice of yoga for people of all ages, skill levels, and geographical locations.

The Yoga Pose Coaching System using Machine Learning effectively addresses the demand for accessible, self-guided yoga practice by providing real-time feedback on posture and alignment without the need for a human instructor. By utilizing computer vision and deep learning techniques, the system can analyze a user's pose, identify discrepancies, and offer corrective feedback, significantly enhancing the accuracy and safety of home-based yoga practice. The system has shown high accuracy in recognizing poses through CNN-based pose estimation and skeletal tracking, achieving approximately 95% recognition accuracy across various yoga poses. This real-time, user-adaptive feedback mechanism enables practitioners to make immediate adjustments, thereby reducing the risk of injury and promoting better alignment. Overall, this system has the potential to make yoga more accessible and personalized, helping users of all experience levels improve their practice safely and effectively.

1. Enhanced Dynamic Pose Tracking

Future iterations should aim to capture transitions and fluid movements in yoga flows, such as vinyasa

sequences, to provide uninterrupted feedback throughout the entire practice. Advanced motion-tracking algorithms or 3D motion-sensing technology could improve dynamic pose detection.

2. Increased Personalization

Integrating more user-specific data, such as flexibility, strength levels, or injury history, could enable even more customized guidance. Using adaptive ML models, the system can provide increasingly refined feedback that considers users' physical abilities and personal progress over time.

3. Mobile and Wearable Device Integration

Expanding the system to mobile platforms and wearable devices (e.g., smartwatches) would enhance accessibility and accuracy, allowing users to practice anywhere. Wearable integration could offer additional data points, such as heart rate and balance, to enhance feedback quality.

4. Diverse and Inclusive Dataset Expansion

Building a more extensive dataset that includes a broader range of body types, genders, ages, and yoga poses will make the system more versatile and inclusive, ensuring accurate feedback across various user demographics.

5. Privacy, Security, and Edge Computing

Ensuring data privacy and security will be crucial as the system collects sensitive body movement data. Implementing edge computing to process data locally, rather than relying on cloud storage, will increase user privacy and reduce latency, making the system faster and more secure.

These advancements will further establish the Yoga Pose Coaching System as a reliable tool for at-home yoga practitioners, making safe and effective practice accessible to a broader audience.

REFERENCES:

- [1] Bukhari M, Bajwa KB, Gillani S, Maqsood M, Durrani MY, Mehmood I, Ugail H, Rho S (2020) An efficient gait recognition method for known and unknown covariate conditions. *IEEE Access* 9:6465–6477.
- [2] Patel SR, Zayas J, Medina-Inojosa JR, Loprinzi C, Cathcart-Rake EJ, Bhagra A, Olson JE, Couch FJ, Ruddy KJ (2021) Real-world experiences with yoga on cancer-related symptoms in women with breast cancer. *Glob Adv Health Med* 10:2164956120984140. <https://doi.org/10.1177/2164956120984140>
- [3] Bilal M, Maqsood M, Yasmin S, Hasan NU, Rho S (2021) A transfer learning-based efficient spatiotemporal human action recognition framework for long and overlapping action classes. *The J Supercomput*. <https://doi.org/10.1007/s11227-021-03957-4>
- [4] [4] Bukhari M, Bajwa KB, Gillani S, Maqsood M, Durrani MY, Mehmood I, Ugail H, Rho S (2020) An efficient gait recognition method for known and unknown covariate conditions. *IEEE Access* 9:6465–6477.
- [5] Chiddarwar GG, Ranjane A, Chindhe M, Deodhar R, Gangamwar P (2020) AI-based yoga pose estimation for android application. *Int J Inn Scien Res Tech* 5:1070–1073
- [6] Cao Z, Hidalgo G, Simon T, Wei SE, Sheikh Y (2019) OpenPose: realtime multi-person 2D pose estimation using part affinity fields. *IEEE Trans Pattern Anal Mach Intell* 43:172–186. <https://doi.org/10.1109/TPAMI.2019.2929257>
- [7] Verma M, Kumawat S, Nakashima Y, Raman S (2020) Yoga-82: a new dataset for fine-grained classification of human poses. *arXiv* [arXiv:2004.10362](https://arxiv.org/abs/2004.10362)
- [8] Chicco D, Jurman G (2020) The advantages of the Matthews correlation coefficient (MCC) over F1 score and accuracy in binary classification evaluation. *BMC Genomics* 21:1–13. <https://doi.org/10.1186/s12864-019-6413-7>
- [9] Bazarevsky V, Grishchenko I, Raveendran K, Zhu T, Zhang F, Grundmann M (2020) BlazePose: On-device real-time body pose tracking. *arXiv* [arXiv:2006.10204](https://arxiv.org/abs/2006.10204)
- [10] Y. Sun, H. Song, X. Ma, W. Liu, Z. Xu, K. Wang, et al., "Collecting and Cleaning Large Scale Agricultural Data for Deep Learning-Based Applications," *Frontiers in Plant Science*, vol. 11, p. 1541, 2020.
- [11] Kendall, A.; Grimes, M.; Cipolla, R. PoseNet: A Convolutional Network for Real-Time 6-DOF Camera Relocalization. *Healthcare* **2021**, 35, 36. [[Google Scholar](#)]
- [12] Chen, H.; Feng, R.; Wu, S. 2D Human pose estimation: A survey. *Multimed. Syst.* **2022**. [[Google Scholar](#)] [[CrossRef](#)]
- [13] Yoga Pose Estimation and Feedback Generation Using Deep Learning, Computational Intelligence and Neuroscience Volume 2022 Publisher Hindawi Limited London, United Kingdom, 2022.
- [14] Bazarevsky V, Grishchenko I, Raveendran K, Zhu T, Zhang F, Grundmann M (2020) BlazePose: Ondevice real-time body pose tracking. *arXiv* [arXiv:2006.10204](https://arxiv.org/abs/2006.10204)
- [15] Review of deep learning: concepts, CNN architectures, challenges, applications, future directions, March 2021 *Journal of Big Data* 8(1) DOI: 10.1186/s40537-021-00444-8.
- [16] Development of a yoga posture coaching system using an interactive display based on transfer learning © The Author(s), under exclusive license to Springer Science Business Media, LLC, part of Springer Nature 2021.

- [17] Yoga-Guru Real-Time yoga pose correction system using deep learning methods 2021 International Conference on Communication Information and Computing Technology (ICCICT), June 2021.
- [18] Yoga Pose Perfection using Deep Learning: An Algorithm to Estimate the Error in Yogic Poses. Journal of Student Research, 10(3), 2021.
- [19] AI-Based Yoga Pose Estimation for android application uploaded by International Journal of Innovative Science and Research Technology Pune- 411041, India Issue 9, September 2020.
- [20] Yoga Pose Detection using deep learning techniques Proceedings of the International Conference on Innovative Computing & Communication (ICICC) 2021.