Research Paper

An Intelligent Fitness Coaching System using Computer Vision and Adaptive Exercise Recommendation

Table of Contents

Abstract

This paper presents the design and development of an intelligent fitness coaching system that leverages computer vision, anthropometric feature extraction, and adaptive recommendation algorithms to generate highly personalized workout programs. The system takes as input a set of 3–8 full-body images of the user captured from multiple angles (front, side, back, and functional poses such as squat or arms raised). Pose landmarks are extracted using the MediaPipe framework, and a set of normalized anthropometric features are computed, including shoulder-to-hip ratios, bilateral asymmetries, and proportional measures of the torso, hips, and lower limbs. These features are analyzed to identify muscular imbalances and structural weaknesses that are often overlooked by conventional fitness applications.

Once weaknesses are detected, the system integrates user-defined variables such as height, weight, fitness goal (strength development, weight loss, or calisthenics), and preferred number of training days per week. A dynamic planning algorithm then constructs a weekly training schedule based on established exercise science principles. Unlike traditional static fitness applications that provide one-size-fits-all templates, the proposed system applies adaptive logic to emphasize underdeveloped muscle groups, balance workload across push, pull, and lower-body sessions, and recommend progressive overload strategies tailored to user ability. Exercise prescriptions are drawn from a curated library of over 250 compound and accessory movements spanning major muscle groups, with metadata on difficulty level, modality, and progression pathways.

Evaluation on pilot cases demonstrates that the system consistently produces realistic, diverse, and scientifically grounded workout plans. Users with lower shoulder-to-hip ratios, for example, received additional pulling and posterior-chain exercises to improve upper-body development, while individuals with hip asymmetries were prescribed unilateral leg and glute activation drills. Preliminary user feedback suggests that the generated plans closely resemble those of a professional trainer in structure and progression, while requiring only inexpensive image-based inputs.

This work highlights the feasibility of low-cost computer vision–based assessments as a foundation for scalable, trainer-like personalization in fitness coaching. Beyond recreational fitness, the framework has potential applications in physical rehabilitation, preventive health, and virtual coaching platforms, thereby contributing to accessible, evidence-based exercise prescription at scale.

Technical Examples

Example 1 — Anthropometric Feature Extraction

Given an uploaded **front-facing photo**, MediaPipe produces 33 keypoints. From these, our pipeline computes normalized metrics:

Shoulder-to-Hip Ratio (norm)=Distance(Lhip,Rhip)Distance(Lshoulder,Rshoulder)/Hpixel

Given an uploaded **front-facing photo**, MediaPipe produces 33 keypoints. From these, our pipeline computes normalized metrics:

- **Case A:** User with shoulder_to_hip_ratio = 0.85 → flagged as *upper-body weakness*.
- **Case B:** User with hip_vertical_asym_norm = 0.05 (>0.03) → flagged as *hip asymmetry*.

Example 2 — Weakness Mapping

Detected weaknesses are mapped to muscle groups:

Weakness Code	Targeted Muscles
upper_body_strength/shoulder_width	Rear delts, upper back
glutes/legs	Glutes, quadriceps, calves
shoulder_asymmetry	Rear delts, scapular stabilizers
hip_asymmetry	Glutes, core stabilizers

This ensures that detected biomechanical issues are addressed with corrective and strengthening work.

Example 3 — Training Day Allocation

If a user selects **5 training days** with a **strength goal**, the planner produces:

Day 1 — Push (Chest/Shoulders/Triceps)

- Bench Press *(compound)*
- Overhead Press *(compound)*
- Incline Dumbbell Press *(accessory)*
- Lateral Raise *(accessory)*
- Skull Crushers *(accessory)*

Day 2 — Pull (Back/Biceps)

- Pull-ups *(compound)*
- Barbell Row *(compound)*
- Lat Pulldown *(accessory)*
- Dumbbell Curl *(accessory)*
- Face Pull *(weakness_fix for shoulders)*

Day 3 — Legs (Glutes/Quads/Calves)

- Squats *(compound)*
- Romanian Deadlifts *(compound)*
- Hip Thrust *(weakness_fix for glutes)*
- Calf Raises *(accessory)*
- Step-ups *(accessory)*

…and so forth.

Example 4 — Set & Rep Prescription

For a **strength-focused beginner**:

- Compound lifts → 4 sets × 6–8 reps
- Accessories → 3 sets × 10–12 reps
- Weakness-fix exercises → 2–3 sets × 12–15 reps (unilateral)

For a **weight-loss goal**:

- Higher-rep circuits (3–4 sets × 12–20 reps)
- Core/mobility finishers (e.g., planks, mountain climbers).

Example 5 — Adaptive Adjustment

- If the system detects **glute weakness**, then:
  - Glutes receive **+2 exercises per week** across split.
  - Example: A "Pull" day may include *Hip Thrust* as weakness_fix.
- If **no weaknesses detected**, plan falls back to balanced PPL (Push/Pull/Legs).

Use Cases of the Proposed System

1. Personalized Fitness Coaching

- Problem: Most fitness apps provide generalized routines that do not adapt to individual body structure.
- System Role: The bot generates training plans that reflect each user's anthropometric ratios, imbalances, and goals (e.g., strength, calisthenics, weight loss).
- Outcome: Users receive trainer-like, individualized guidance without requiring human supervision.

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2. Weakness and Imbalance Correction

- Problem: Structural asymmetries (e.g., uneven shoulders, hip tilt) often go undetected, increasing risk of injury.
- System Role: By analyzing multi-angle body images, the system identifies weaknesses and prescribes targeted corrective or accessory exercises (e.g., unilateral glute bridges for hip imbalance).
- Outcome: Safer, more balanced development with preventive injury focus.

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3. Adaptive Weekly Programming

- Problem: Predefined 3-day or 5-day plans do not adjust for training frequency or user progression.
- System Role: The system generates dynamic splits (Push/Pull/Legs, Bro Split, or Focus Days) depending on available training days (4/5/6) and detected weaknesses.
- Outcome: Training adapts to user lifestyle while maintaining scientific principles of periodization and progressive overload.

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4. Equipment-Agnostic Training

- Problem: Users vary in gym access — some train at home, others at full gyms.
- System Role: Exercise recommendations are drawn from a large library that can be filtered by available equipment (bodyweight-only, dumbbells, resistance bands, barbell).
- Outcome: Flexibility for home workouts, gym training, or hybrid setups.

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5. Scalable Virtual Coaching

- Problem: Hiring human trainers does not scale across populations.

- System Role: The system uses inexpensive computer vision (only requiring phone images) to provide automated coaching.
- Outcome: Affordable, globally accessible personal training, even in resource-constrained settings.

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6. Rehabilitation and Preventive Health

- Problem: Rehab patients often need corrective exercise guidance but lack access to physiotherapists.
- System Role: Weakness detection rules can be extended to monitor posture deviations and suggest low-impact corrective exercises.
- Outcome: Support for rehabilitation, recovery, and preventive care in musculoskeletal health.

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7. Data-Driven Research Platform

- Problem: Current fitness datasets lack anthropometric progression data at scale.
- System Role: With consent, anonymized features and training logs can create a dataset of body proportions and training adaptations.
- Outcome: Opens new research avenues in biomechanics, body composition analysis, and adaptive training algorithms.

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1. Introduction

In recent years, there has been a growing demand for personalized fitness coaching as individuals increasingly seek training programs that account for their unique body types, goals, and constraints. While professional personal trainers can deliver customized programs, the high cost of one-on-one coaching and limited accessibility in many regions make such services unattainable for a large segment of the population. At the same time, the rise of fitness mobile applications and online platforms has attempted to address this demand. However, most commercial fitness apps rely on rigid, predefined workout templates that are generalized for broad audiences. These solutions fail to incorporate individual biomechanics, muscular imbalances, or body asymmetries, which are critical factors in safe and effective training.

To overcome these limitations, this paper introduces an AI-powered gym trainer bot that combines computer vision–based pose estimation with adaptive workout planning. By analyzing multiple full-body images of a user, the system extracts anthropometric features such as shoulder-to-hip ratios, joint alignments, and symmetry metrics. These features are then used to detect structural weaknesses, which are integrated into the program design. Unlike conventional fitness applications, our approach dynamically tailors weekly training splits to the individual, thereby ensuring balanced development and progressive overload tailored to personal goals.

The main contributions of this work are as follows:

1. *We design a computer vision–based anthropometric analysis pipeline that operates on user-uploaded images without requiring specialized equipment.*
2. *We propose a weakness detection framework that maps observed asymmetries and imbalances to specific muscle groups, enabling corrective exercise integration.*
3. *We implement a dynamic weekly workout plan generator that accommodates different training frequencies (4-, 5-, or 6-day splits) while maintaining exercise science principles.*
4. *We integrate a curated exercise library of over 250 compound and accessory movements, ensuring that the recommendations are varied, progressive, and aligned with the user's fitness objectives.*

Through this work, we demonstrate that computer vision techniques combined with adaptive planning algorithms can provide a scalable, low-cost alternative to traditional personal training, bringing individualized coaching within reach for a global audience.

2. Related Work

Pose Estimation for Fitness

Recent advances in computer vision have enabled pose estimation systems such as OpenPose [1] and MediaPipe [2], which can detect human skeletal key points in real time. In the fitness domain, these tools have primarily been applied to rep counting and posture correction tasks. For example, prior works have focused on detecting squats or push-ups to assess form accuracy and automate repetition tracking. While valuable for basic exercise monitoring, these systems do not extend to comprehensive program design or personalized training adaptation based on body structure.

Exercise Recommendation Systems

Beyond pose estimation, research in exercise recommendation has generally followed approaches similar to those used in music or product recommendation systems. Collaborative filtering, clustering, and knowledge-based filtering have been applied to suggest workouts based on user preferences or demographic similarity [3,4]. However, such methods rarely incorporate biomechanical features or structural imbalances of the user. As a result, the recommendations often remain generic and do not address individualized weaknesses or asymmetries, which are critical for injury prevention and balanced progression.

Digital Personal Trainers

Commercial fitness applications such as Fitbod, Freeletics, and Nike Training Club have made personalized training more accessible. These platforms typically rely on user surveys, fitness questionnaires, or self-reported experience levels to generate workouts. While convenient, these systems are limited by their self-reported input data and lack the ability to objectively assess a user’s physique or biomechanics. Consequently, they cannot provide tailored corrections for structural imbalances or weak muscle groups.

Research Gap

To the best of our knowledge, no existing system provides an end-to-end pipeline that (1) analyses anthropometric features from full-body images, (2) detects muscular weaknesses or asymmetries, and (3) generates split-periodized weekly workout plans that adapt to user goals and training frequency. Our work addresses this gap by integrating pose-based analysis with dynamic plan generation, thereby moving beyond form correction or survey-based customization to deliver trainer-like personalization at scale.

3. Methodology

3.1 Data Collection

The system requires users to upload 3–8 full-body images captured from multiple angles to provide sufficient coverage for anthropometric analysis. Recommended poses include front-facing, side profiles (left and right), rear view, and functional postures such as a squat or arms raised overhead. These diverse perspectives allow the system to more reliably capture skeletal landmarks and detect asymmetries that may not be visible from a single image. In addition to the images, users are prompted to enter basic attributes including height, weight, and a training goal (e.g., strength development, calisthenics, or weight loss). These inputs serve as contextual information for normalizing pose features and tailoring the workout plan.

3.2 Pose Estimation and Feature Extraction

Pose estimation is performed using MediaPipe Pose, which extracts 33 body landmarks including key joints and skeletal reference points. From these landmarks, several normalized anthropometric features are derived:

- Shoulder, hip, and ankle widths relative to estimated body height.
- Vertical asymmetries between left and right shoulders or hips, indicating postural misalignments.
- Proportional ratios, such as the shoulder-to-hip ratio, which are often used in biomechanics to characterize body structure.

Normalization by body height ensures that features are comparable across individuals regardless of camera distance or image resolution.

3.3 Weakness Detection

The extracted features are analyzed using rule-based heuristics that map numerical values to potential structural weaknesses:

- A low shoulder-to-hip ratio is interpreted as underdeveloped upper body musculature.
- Narrow hips relative to shoulders suggest glute and leg underdevelopment.
- Vertical asymmetry thresholds (e.g., >3% deviation between left and right sides) indicate imbalances in the shoulders or hips.

Each weakness is then linked to a set of target muscle groups requiring additional emphasis in the training program.

3.4 Exercise Library

The system incorporates a curated exercise library of approximately 270 exercises spanning nine major muscle groups. Each exercise entry is annotated with metadata including:

- id and name (unique identifier and exercise label).
- muscle_group (primary target).

- difficulty (beginner, intermediate, advanced).
- type (strength, mobility, stability).
- progression (links to simpler or more advanced variations).

Exercises are further classified into compound movements (multi-joint lifts such as squats and presses) and accessory movements (isolated or corrective drills). This structure supports flexible plan generation with both variety and progression.

3.5 Plan Generation

Based on the user's selected training frequency (4, 5, or 6 days per week), the system applies predefined split templates such as Push/Pull/Legs, body-part split, or inclusion of a focus day. The plan generation algorithm ensures that each training session contains:

- 1–2 compound lifts for major muscle groups.
- 2–3 accessory exercises for hypertrophy or balance.
- 1 weakness-fix exercise targeting asymmetries or underdeveloped areas.

When a muscle group is prioritized due to weakness detection, it may receive additional exercises across the week or a dedicated training day. Repetition ranges and set prescriptions are adjusted using progressive overload principles, varying with the chosen goal (e.g., low reps/high weight for strength, high reps/short rest for weight loss).

3.6 System Architecture

The system is implemented as a modular web application. The frontend is developed using Flask with HTML/CSS templates for user interaction. The backend is built in Python, leveraging MediaPipe for pose estimation, OpenCV for image handling, and NumPy for feature computation. The exercise database is stored in JSON format, ensuring portability and easy extensibility. For deployment, the application is containerized with Docker, enabling seamless scaling to cloud environments and integration into mobile or web APIs.

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4. Results

4.1 Case Study 1 — Glute Weakness

In the first case, **Subject A** exhibited a low hip-to-shoulder width ratio, indicating underdeveloped glutes and lower-body musculature. The weakness detection module flagged "glutes/legs" as a priority muscle group. Consequently, the weekly program included targeted glute activation and strengthening exercises. Specifically, the algorithm injected **glute bridges** and **hip thrusts** across three separate training days, in addition to standard compound lifts such as squats and deadlifts. This ensured that the user received both direct and indirect glute stimulation, aligning with established hypertrophy and corrective training practices.

4.2 Case Study 2 — Shoulder Asymmetry

Subject B presented with a measurable vertical misalignment between the left and right shoulder landmarks. The system categorized this as "shoulder asymmetry," which mapped to corrective and stabilizing muscle groups, including the rear delts and upper back. In response, the program integrated **unilateral lateral raises** and **face pulls** to strengthen scapular stabilizers and address muscular imbalances. Importantly, these were placed alongside primary pulling movements to ensure balanced load distribution across sessions.

4.3 Program Coherence

Across both case studies, the generated plans demonstrated coherence with **classical training principles**:

- Each day contained at least one **compound movement** for strength and functional carryover.
- Accessory and isolation movements were layered to address specific weaknesses.
- Exercise volume and intensity progressed logically with the user's goal (strength, weight loss, or calisthenics).
  This indicates that the system not only adapts to detected weaknesses but also preserves overall program integrity.

4.4 Pilot Evaluation

An early pilot evaluation was conducted with **five volunteer users** who tested the system with their own images and goals. After receiving their personalized plans, participants were asked to rate outputs on a **5-point Likert scale**.

- **Realism of the program** (how closely it resembled a trainer-designed plan) was rated **4.2/5** on average.
- **Personalization quality** (relevance of exercises to individual body structure and goals) scored even higher, at **4.4/5**.

These preliminary results suggest that the proposed system can generate workout plans that users perceive as both realistic and meaningfully tailored, despite relying solely on image-based analysis and simple rule-based heuristics.

5. Discussion

5.1 Strengths

Scalability and accessibility.
Because the system relies only on inexpensive full-body images and lightweight computer vision, it is accessible to users who cannot afford personal trainers or live in areas with limited fitness infrastructure. The architecture can scale to serve large user populations via web or mobile deployment without significantly increasing costs.

Integration of corrective emphasis.
Unlike traditional fitness apps that offer rigid templates, the proposed system actively identifies muscular weaknesses and asymmetries and integrates corrective or accessory exercises into the weekly plan. This allows for more targeted training and addresses imbalances that could otherwise persist or worsen over time.

Exercise variety.
With a curated library of over 250 compound and accessory movements, the system can generate diverse workout plans, reducing monotony and enabling progression across different muscle groups and difficulty levels.

5.2 Weaknesses

Heuristic-based weakness detection.
At present, the detection of weaknesses is based on rule-based thresholds (e.g., shoulder-to-hip ratio, asymmetry percentages). While effective in simple cases, such heuristics cannot capture complex biomechanical patterns or individual differences that a data-driven machine learning model could identify.

Lack of injury risk assessment.
The system does not currently account for pre-existing conditions, joint issues, or injury history. As a result, certain recommended exercises may not be safe for all users. Without incorporating injury modeling, the recommendations should be viewed as general guidance rather than medically certified prescriptions.

Absence of real-time feedback.
Although the system designs detailed programs, it does not evaluate execution quality during training. Real-time assessment of repetitions, range of motion, or form correction is absent, which limits its ability to prevent poor technique or provide on-the-spot guidance — an area where other CV-based fitness tools are already advancing.

Dependence on image quality.
The accuracy of anthropometric measurements depends on the clarity, lighting, and angle of uploaded images. Suboptimal photos can lead to inaccurate landmark detection, which in turn may affect weakness analysis and program design.

6. Future Work

The present system demonstrates the feasibility of using computer vision and rule-based heuristics for automated workout plan generation. However, several opportunities exist to enhance accuracy, adaptability, and user experience.

Integration of machine learning classifiers.
Currently, weakness detection relies on simple anthropometric thresholds. In future iterations, supervised learning models trained on **labeled datasets of body proportions and training outcomes** could provide more nuanced assessments. Such models would capture subtle patterns beyond rule-based logic and improve the personalization of exercise recommendations.

Equipment availability filters.
The current exercise library assumes general availability of gym equipment. To increase usability in diverse contexts, future versions should include filters for **home-based vs. gym-based training**, tailoring recommendations based on available resources (e.g., bodyweight-only plans, resistance bands, dumbbell-only workouts).

Conversational interfaces.
To enhance engagement, the system could be extended with a **voice- or text-based chatbot interface**. This would allow users to interact with the system conversationally, ask clarifying questions, and receive explanations about why particular exercises were recommended, making the tool feel more like a human trainer.

Real-time form correction.
While the current system analyzes static images, future versions could incorporate **live video feedback** to assess exercise execution. By leveraging pose estimation in video streams, the system could detect deviations in form, count repetitions, and provide immediate corrective guidance — a feature increasingly expected in next-generation digital coaching platforms.

Longitudinal adaptation via reinforcement learning.
Workout programming is an iterative process that adapts over time. Incorporating **reinforcement learning** would enable the system to evolve recommendations based on user adherence, performance improvements, and feedback. This would shift the system from generating one-off plans to supporting **long-term training progression**, mirroring the adjustments made by human coaches.

7. Conclusion

This work demonstrates the feasibility of developing an **AI-based gym trainer bot** that integrates computer vision, anthropometric feature extraction, and adaptive workout planning. By leveraging pose estimation on user-uploaded full-body images, the system can extract meaningful structural features, detect muscular weaknesses, and design personalized training programs without the need for costly equipment or human trainers.

A key strength of the approach lies in its ability to **emphasize underdeveloped muscle groups** and integrate corrective exercises into coherent weekly splits, thereby moving beyond static templates toward **trainer-like personalization**. The system preserves classical training principles, including balanced push–pull–leg distribution, progressive overload, and variation through compound and accessory movements, while still adapting to user-specific weaknesses.

The preliminary case studies and pilot feedback indicate that the generated workout plans are perceived as both **realistic** and **personalized**, validating the potential of image-based assessments in fitness coaching. Although current limitations include heuristic-based weakness detection, lack of injury modelling, and absence of real-time feedback, these constraints point to clear avenues for future improvement.

Overall, the proposed system offers a promising foundation for **democratizing access to individualized fitness coaching at scale**. With further integration of machine learning, real-time video feedback, and longitudinal adaptation, the framework could evolve into a comprehensive digital trainer capable of supporting recreational fitness, rehabilitation, and preventive health applications.

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