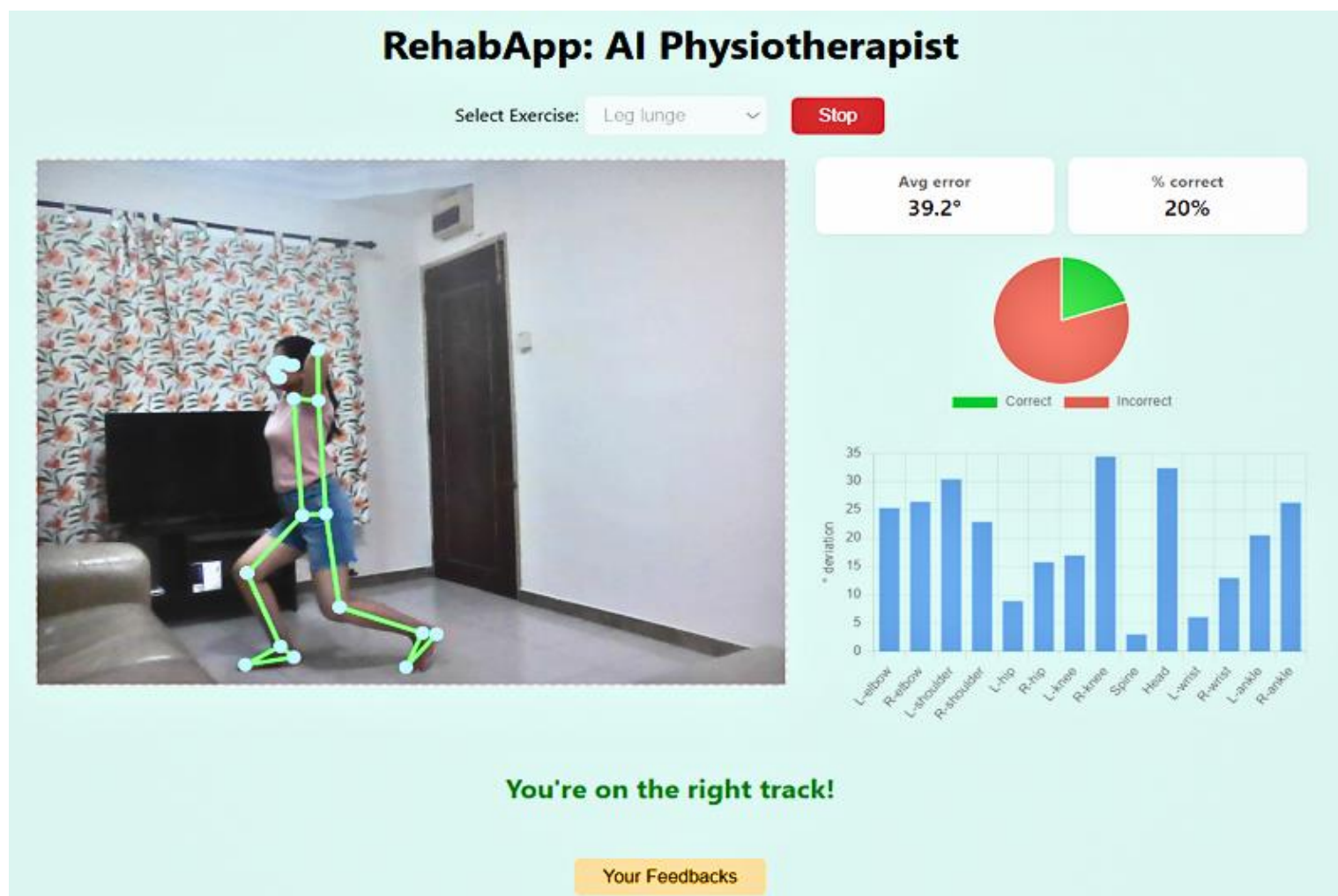


Pose Correction System for Physical Therapy and Rehabilitation Using Computer Vision



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NUS-ISS, National University of Singapore**

Motivation: Why home Physical Therapy still needs a coach

Widespread form errors

- 55% of patients perform ≥ 1 drill incorrectly ¹
- Errors usually go unnoticed at home

Real clinical impact

- Mis-execution delays healing
- Re-injury risk increases when cues are missed

Most tools fall short

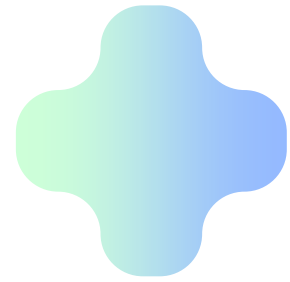
- Binary pass / fail feedback \Rightarrow no guidance
- Cloud / GPU needed \Rightarrow cost, latency, privacy

Lightweight way forward

- Real-time, joint-level, spoken advice on any laptop
- Summarizations and Analysis



¹ Faber et al., PeerJ 2015 ² Almalty et al., Sport TK 2025.



Improving Rehabilitation : AI-Powered Physical Therapy

Technical problem

- Laptop-only CV system, must spot 14 joint-angle errors and speak corrective cues in $< 0.5s$ at $\geq 90\%$ accuracy.

Business upside

- Cuts therapist load and follow-up visits \rightarrow lower costs
- Scales telerehab to thousands without cloud / GPU fees

Impact for Singapore

- Shrinks wait-times for an ageing, physio-heavy population
- Backs Healthier SG & Smart-Nation tele-medicine goals



Key Contributions: RehabApp - AI Physiotherapist

Lightweight Architecture

3-head CNN + Bi-LSTM, only
3.4 M parameters

Granular Feedback

Joint-level advice on 14
angles – not just pass/fail

Built-in Safety

“Wrong-exercise” guard
blocks unsafe cues
automatically

Real-time & Open

handles 30 video fps on a
mid-range CPU; Open-
source React + FastAPI



Dataset: REHAB24-6²

Key facts	Details
Purpose	Benchmark pose-estimation & exercise-quality algorithms under real rehab conditions
Subjects & drills	10 adults (6 ♂ / 4 ♀, 25–50 y) perform 6 physiotherapy exercises Arm-abduction, Arm-VW, Push-ups, Leg-abduction, Lunge, Squats
Volume	65 recordings = 184,825 frames
Ground-truth	41-marker 3-D mocap Derived 26-joint skeleton in 3-D & 2-D Synced RGB videos
Why we chose it	Contains both visual & Motion-Capture Ground Truth (mocap GT) Balanced correct/wrong reps Multiple views → tests occlusion robustness

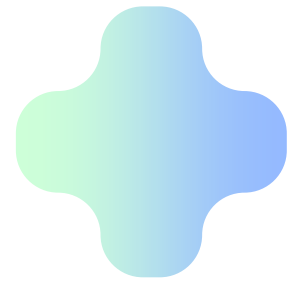
Exercise ID	Reps	Correct	Wrong	Frames
1	178	90	88	27 442
2	208	94	114	33 641
3	107	52	55	12 054
4	210	120	90	18 329
5	174	78	96	17 608
6	195	134	61	19 373
Total	1 072	568	504	128 447

Summary Table

video_id	repetition_nui	exercise_id	person_id	first_frame	last_frame	cam17_orient	mocap_erron	exercise_sublights_on	extra_person	extra_person	correctness	
PM_001	1	1	1	130	324	front	0	right arm	0	1	0	1
PM_001	2	1	1	325	537	front	0	right arm	0	1	0	1
PM_001	3	1	1	538	731	front	0	right arm	0	1	0	1
PM_001	4	1	1	732	919	front	0	right arm	0	1	0	1
PM_001	5	1	1	920	1090	front	0	right arm	0	1	0	1
PM_001	6	1	1	1690	1940	front	0	right arm	0	1	0	0
PM_001	7	1	1	2060	2346	front	0	right arm	0	1	0	0
PM_001	8	1	1	2347	2554	front	0	right arm	0	1	0	0
PM_001	9	1	1	2555	2746	front	0	right arm	0	1	0	0
PM_001	10	1	1	2747	2961	front	0	right arm	0	1	0	0
PM_002	1	1	1	152	363	half-profile	0	right arm	0	1	0	1
PM_002	2	1	1	364	573	half-profile	0	right arm	0	1	0	1
PM_002	3	1	1	574	766	half-profile	0	right arm	0	1	0	1
PM_002	4	1	1	767	910	half-profile	0	right arm	0	1	0	1
PM_002	5	1	1	1000	1225	half-profile	0	right arm	0	2	0	0
PM_002	6	1	1	1226	1407	half-profile	0	right arm	0	2	0	0
PM_002	7	1	1	1408	1605	half-profile	0	right arm	0	1	0	0
PM_002	8	1	1	1606	1800	half-profile	0	right arm	0	1	0	0
PM_002	9	1	1	1801	1967	half-profile	0	right arm	0	2	0	0

Author-supplied frame-level segmentation

² Černek A. et al., “REHAB24-6: Dataset for Analyzing Pose Estimation Methods,” Springer LNCS, 2024.



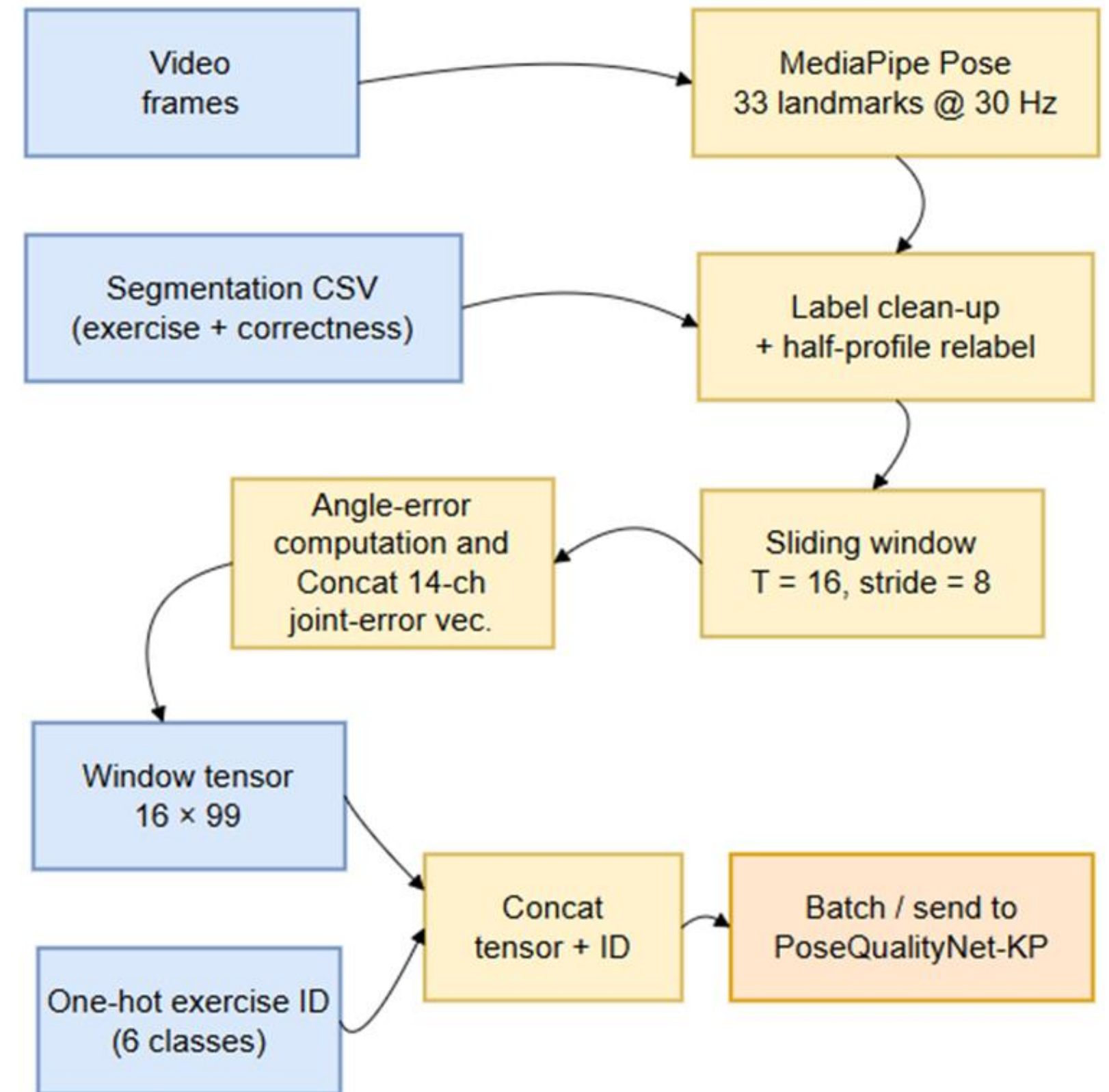
Data: Augmentations and Pipeline

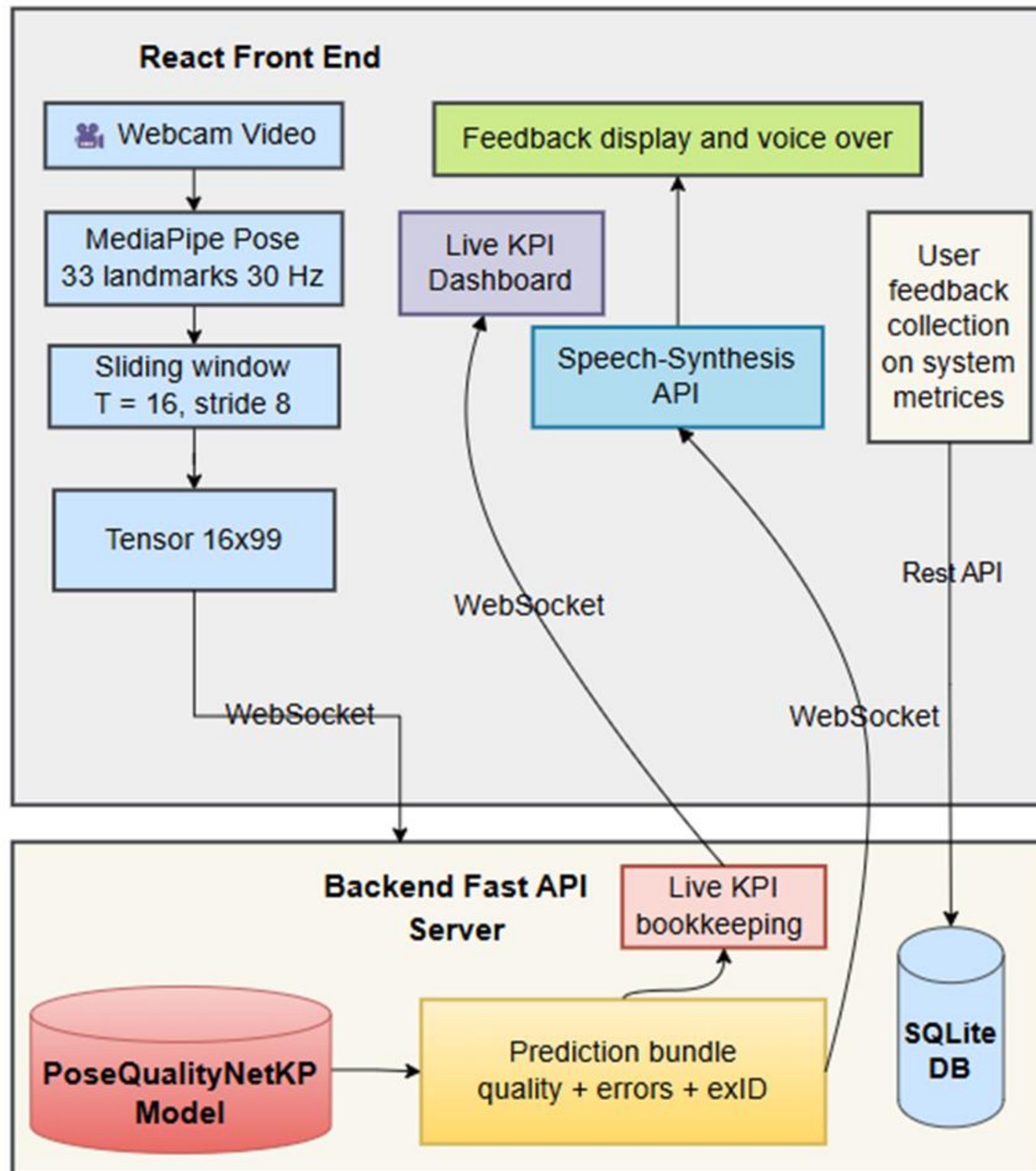
Temporal & Label Augmentations

- Sliding window $T = 16$ frames, stride = 8 \rightarrow $\times 8$ more samples
- Half-profile relabel
- Oblique views auto-marked incorrect (for 5 / 6 drills)

Feature Engineering

- 99-D vector / frame (33 key-points \times 3 coords)
- One-hot exercise ID (6 classes) appended once per window
- 14 joint-angle errors kept as labels for the regression head





System Architecture:

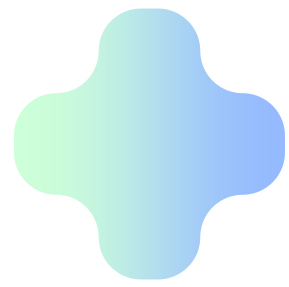
End-to-End Overview

Front-end (React, runs in browser)

- Captures 640 × 480 webcam video and runs MediaPipe Pose @ 30 Hz
- Builds 16 × 99 tensors + one-hot exercise ID; streams them via WebSocket
- Renders colour-coded skeleton, speaks cues (Speech-Synthesis API) and shows live KPI dashboard

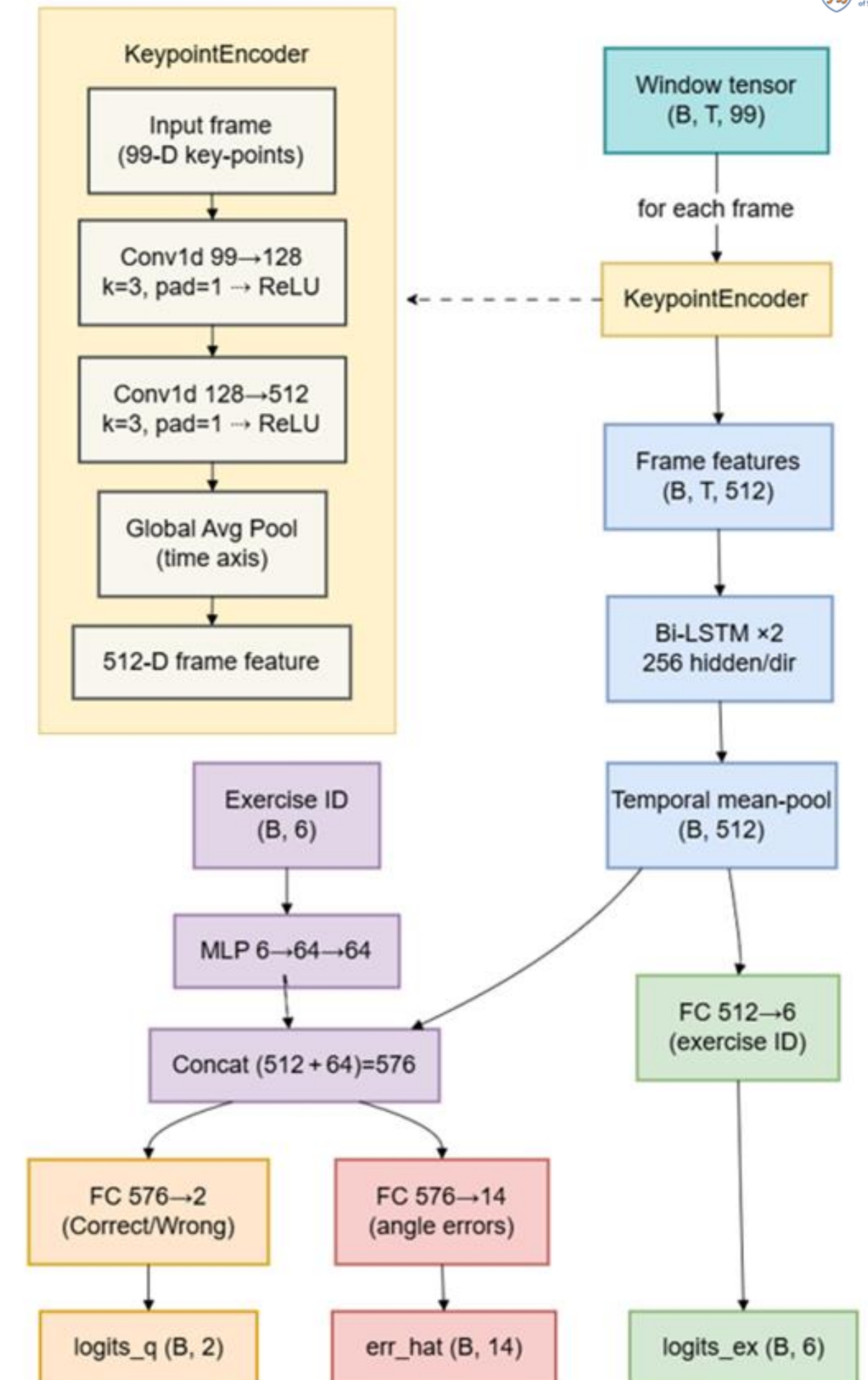
Back-end (FastAPI, on same laptop)

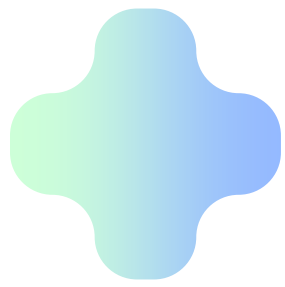
- Hosts PoseQualityNet-KP → predicts quality, 14 joint-angle errors & exercise ID in ≈ 2 ms
- Majority-vote buffer (5 windows) suppresses flicker; “wrong-exercise” guard blocks unsafe advice
- Sends compact JSON to front-end, logs KPIs & survey answers in SQLite (REST endpoint)



Model Architecture: PoseQualityNet-KP

Block	Shape / Notes
Key-point encoder	1-D CNN 99 \rightarrow 128 \rightarrow 512
Temporal encoder	2-layer Bi-LSTM (256 h / dir)
Exercise embedding	6 \rightarrow 64 MLP
Prediction heads	quality (2-way) • angle errors (14-D) • exercise (6-way)
Footprint	3.41 M params \approx 13 MB





Model Training: PoseQualityNet-KP

Dataset & split

- 14375 overlapping 16-frame windows from the cleaned REHAB24-6 corpus
- Subject-stratified 70 / 15 / 15 % Train / Val / Test

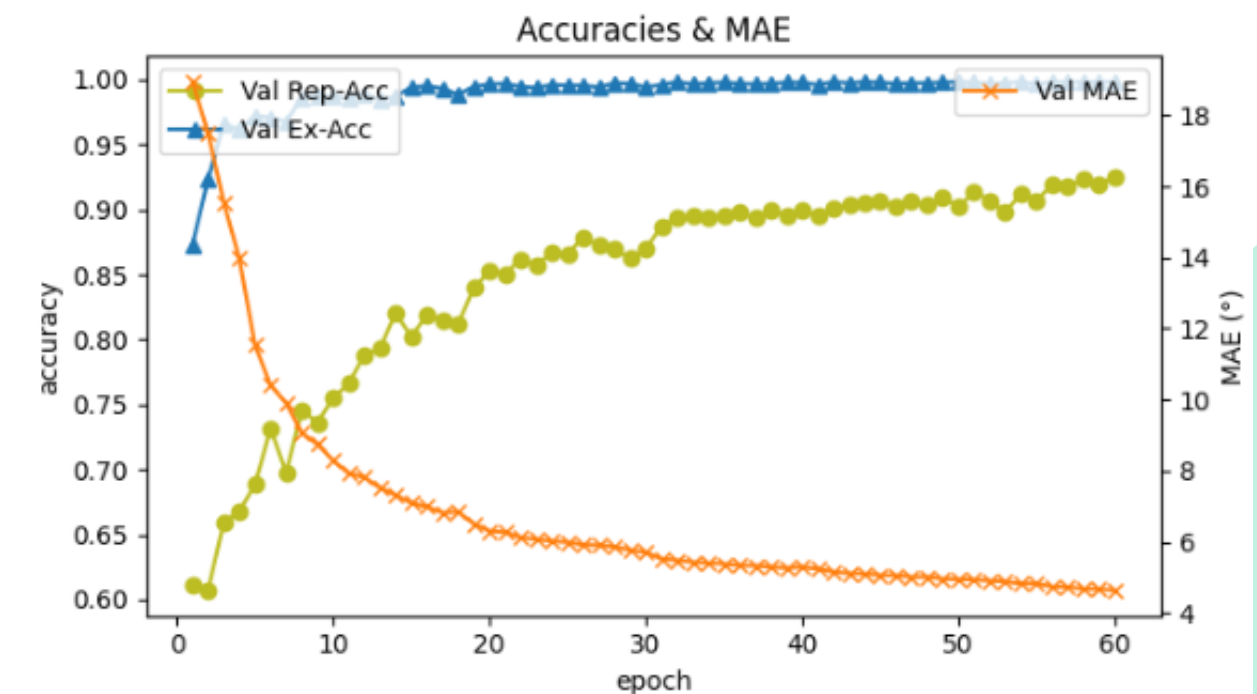
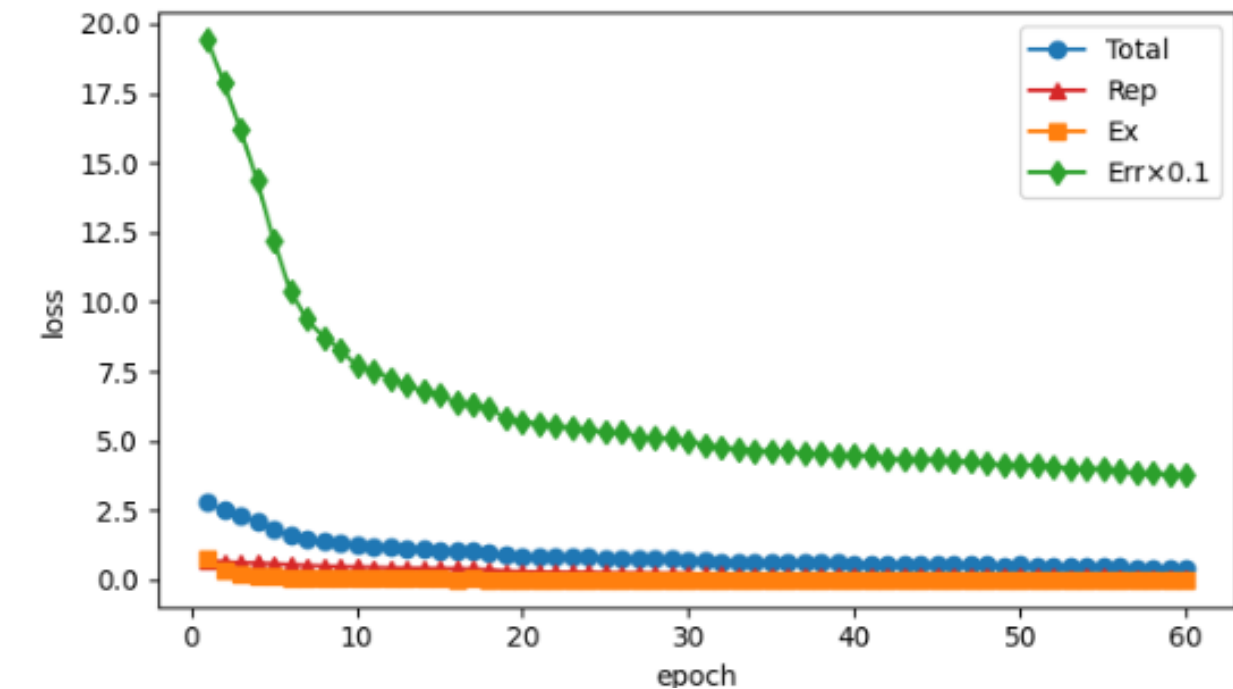
Optimisation

- AdamW – LR 3×10^{-4} , weight-decay 10^{-2}
- Batch 32 windows (~4 kB ea); gradient clip $\|g\|_2 \leq 1.0$

$$\text{Loss } \mathcal{L} = \mathcal{L}_{rep} + 0.2 \mathcal{L}_{ex} + 0.1 \mathcal{L}_{err}$$

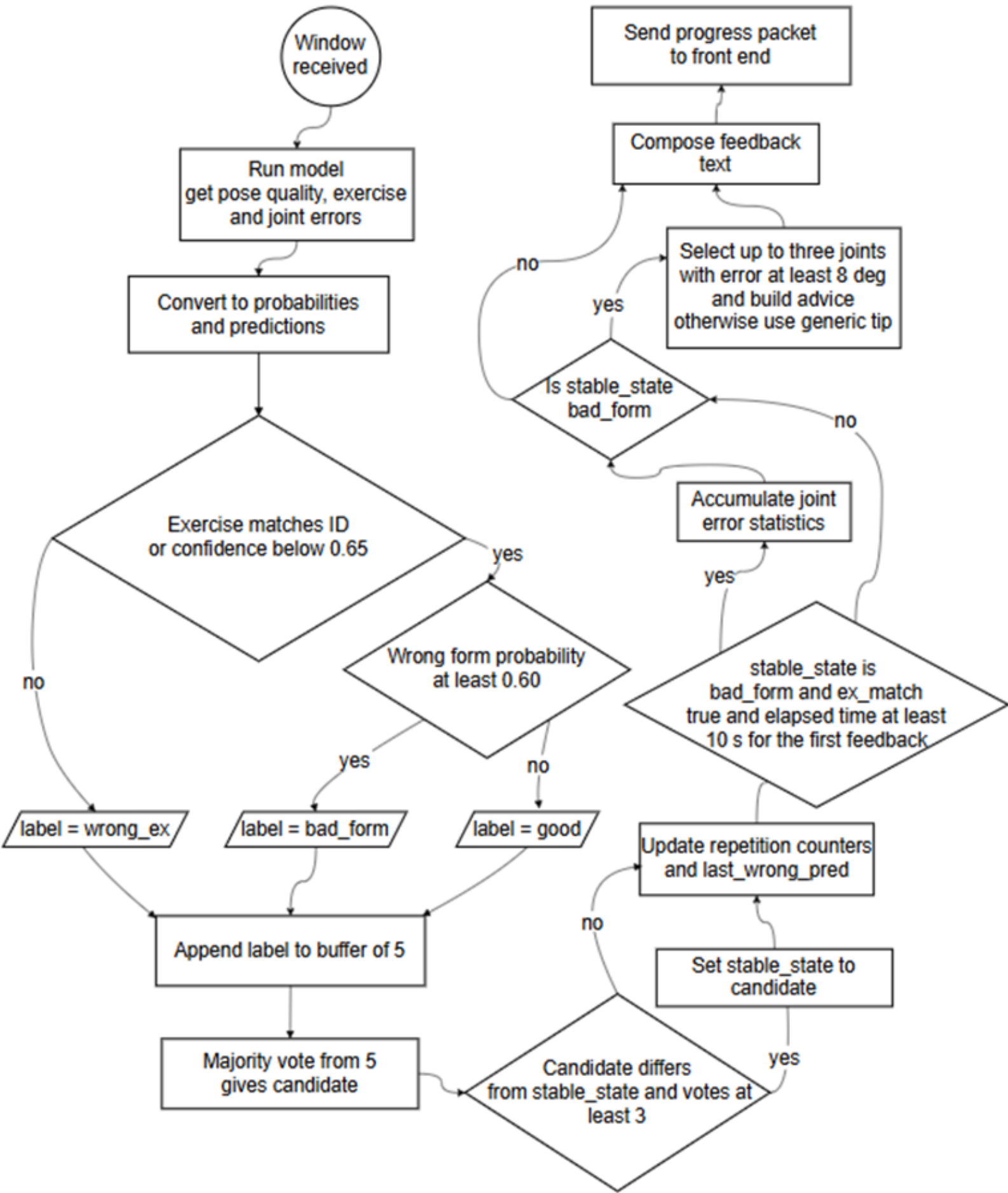
Training time / hardware

- 30-35 epochs (≈ 40 min) on a consumer Apple M4 laptop (16 GB RAM)
- Same code runs unchanged on RTX 3060



Inference: Feedback Logic

Scenario	Example sentences	How they are produced
Correct form	<p>Feedback : “You’re on the right track!”</p> <p>Suggestion : —</p>	<p>1. Quality head $\Rightarrow p(\text{wrong}) < 0.60$ and exercise ID agrees with the drop-down \rightarrow state = good.</p> <p>2. All joint errors $< 8^\circ \rightarrow$ corrections list is empty.</p>
Bad form	<p>Feedback : “You’re doing it wrongly!”</p> <p>Suggestion (example): “Adjust your left hip, spine and right ankle properly.”</p>	<p>1 $p(\text{wrong}) \geq 0.60$ and exercise matches with selected \rightarrow state = bad_form</p> <p>2 Keep joints with $\Delta\theta \geq 8^\circ$, sort by magnitude, take top 3 \rightarrow e.g. {left-hip, spine, right-ankle}.</p>
Wrong exercise	<p>Feedback : “Wrong exercise! Looks like Push-ups.”</p> <p>Suggestion : —</p>	<p>1 Exercise head \neq selected and $\text{conf} \geq 0.65 \rightarrow$ state = wrong_ex</p> <p>2 Skip joint-error logic entirely.</p>



Results : Quantitative

Window-level performance (4112 test windows)

- Repetition quality: Acc 91.5 %, F1_w 0.915
- Exercise ID: Acc 99.5 %, F1_w 0.995
- Joint-angle error MAE: 4.73° across 14 DoF

Efficiency & footprint

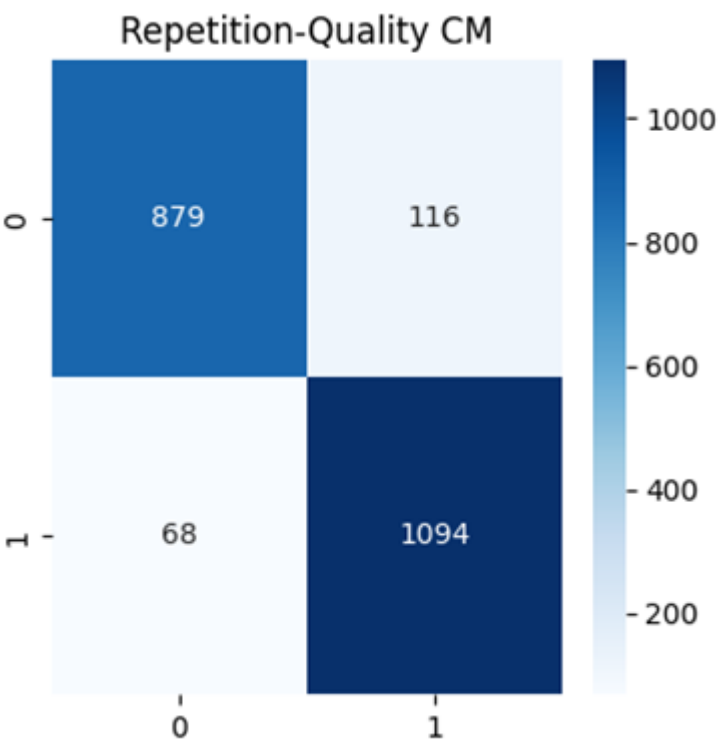
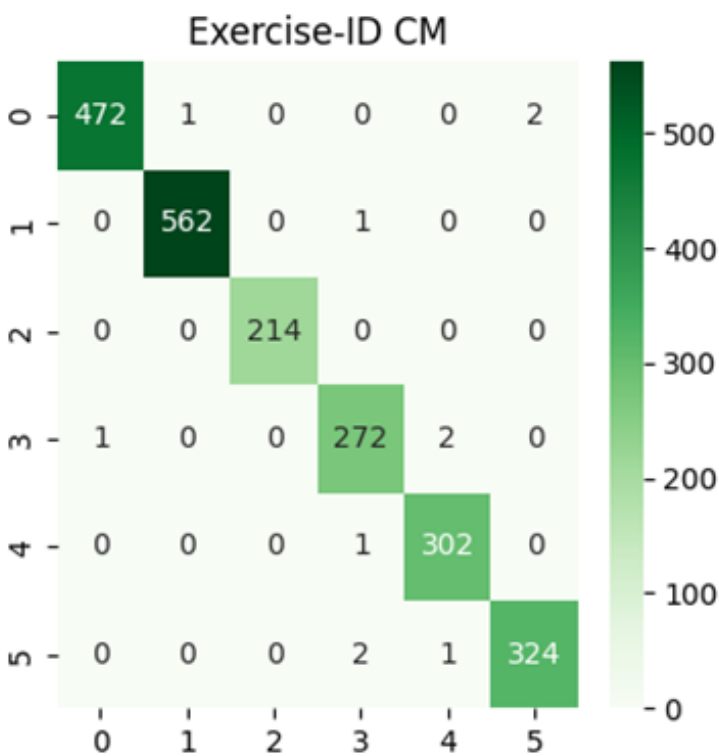
- 7500 windows s⁻¹ ≈ 30 fps end-to-end on mid-range CPU
- 3.41M parameters (< 8MB), no GPU required
- Latency: ≈ 2.5 ms (browser → server → browser)

Confusion-matrix take-aways

- Rep-quality: TP: 1094, TN: 879, FP: 116, FN: 68
- Exercise ID: only 5 mis-labels
- largest confusion Arm-VW ↔ Arm-Abduction
- 93 % of windows give clinically actionable (< 5°) angle errors

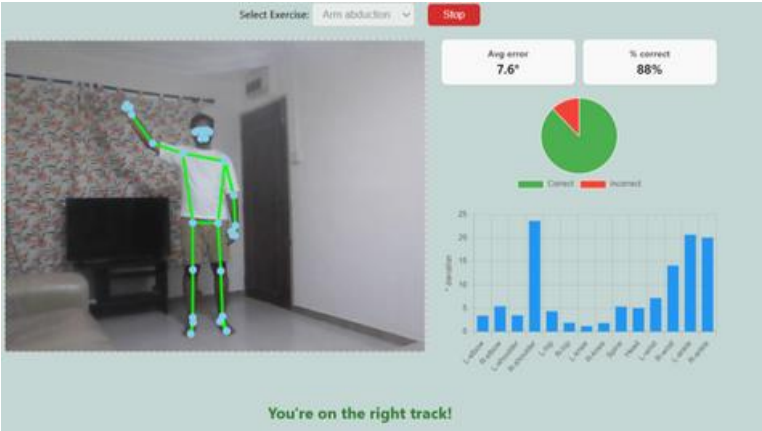
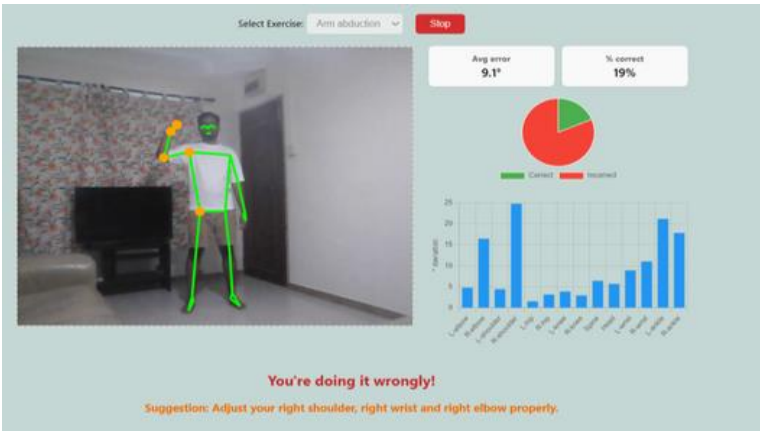
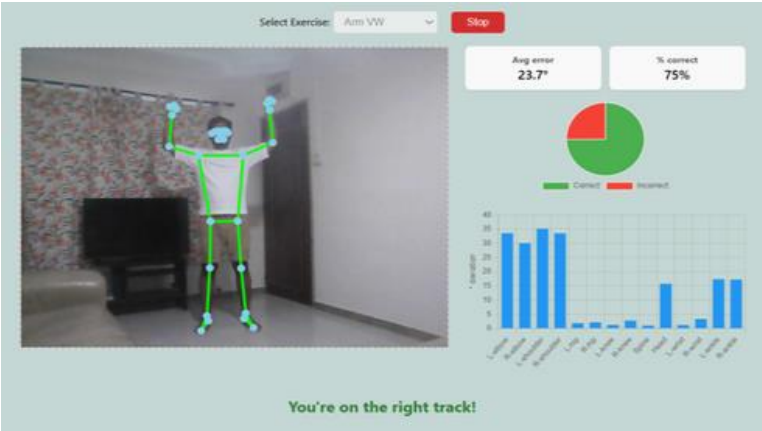

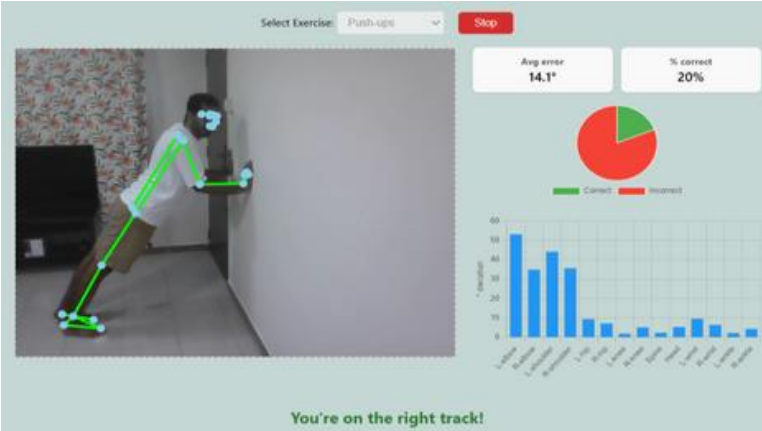

Efficiency & footprint

- Mobile-ready: real-time, < 10 MB, runs on-device
- Rich feedback: joint-level errors + wrong-exercise guard
- State-of-the-art accuracy on six diverse rehab drills



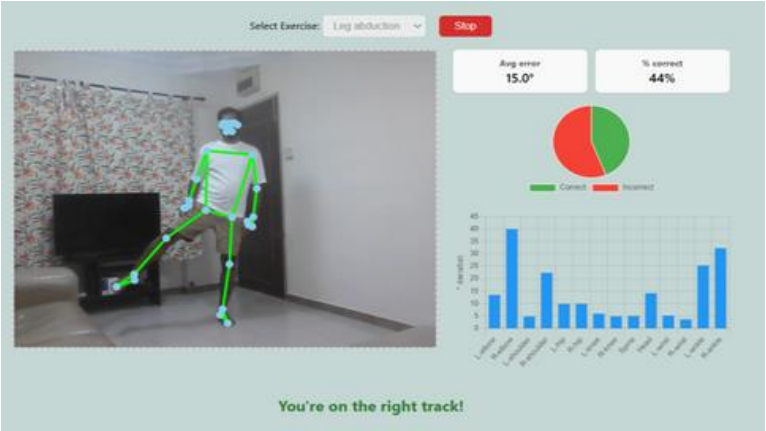

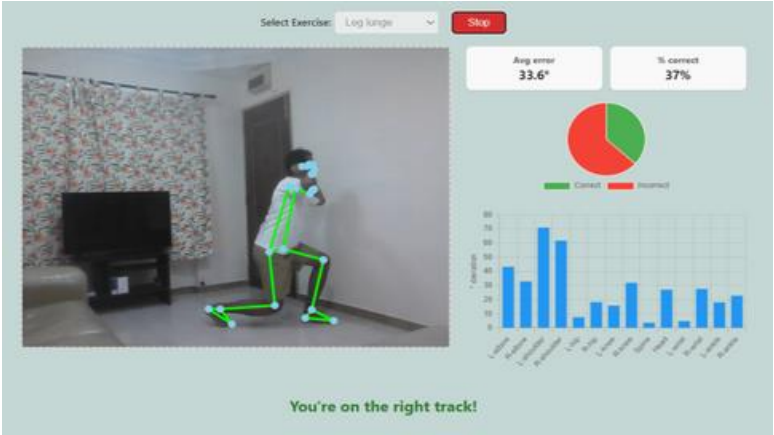
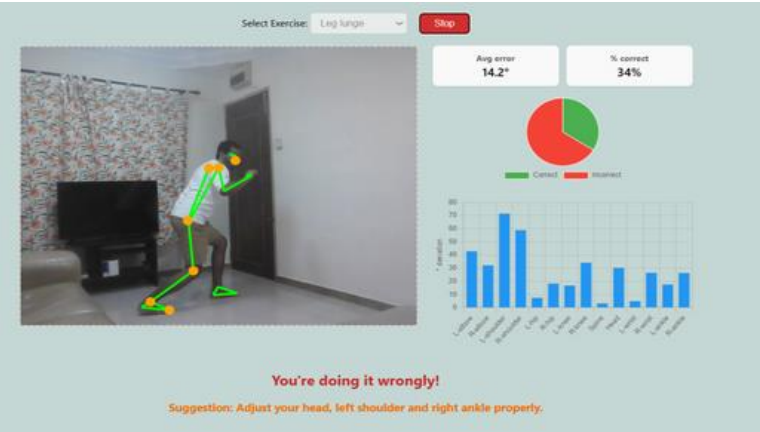
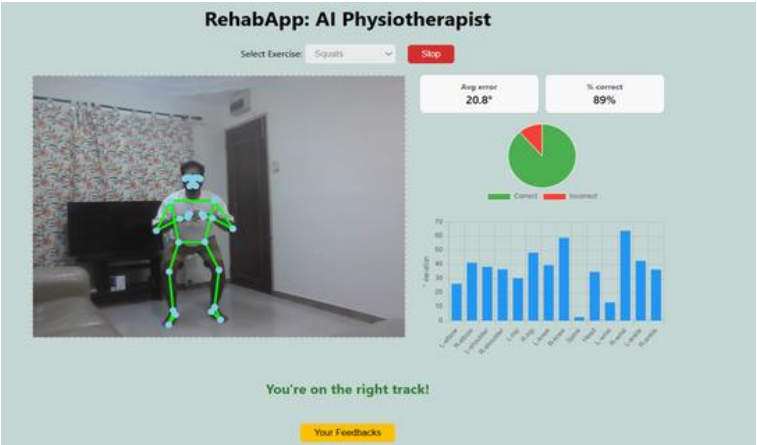
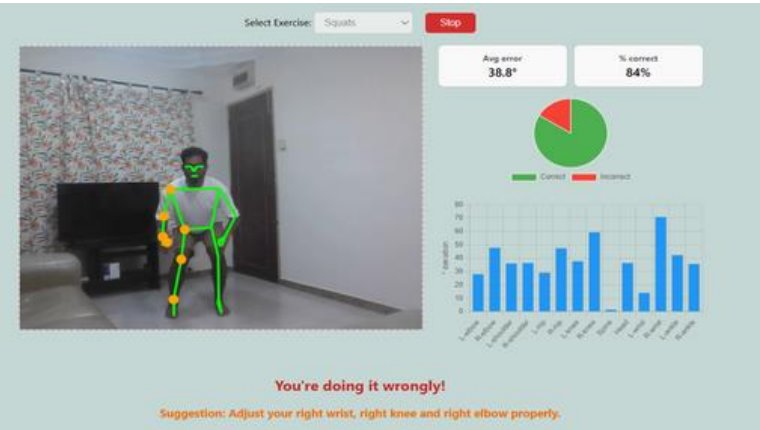
Head	Acc	F1_w	MAE (°)
Rep-quality	0.915	0.915	–
Exercise ID	0.995	0.995	–
Angle error	–	–	4.73

Results : Qualitative

Exercise	Correct Form	Incorrect Form	Feedback/Suggestion
Ex1: Arm-abduction			<p>Correct form: “You’re on the right track”</p> <p>Incorrect form : “You’re doing it wrongly!” “Suggestion: Adjust your right shoulder, right wrist and right elbow properly”</p>
Ex2: Arm-VW			<p>Correct form: “You’re on the right track”</p> <p>Incorrect form : “You’re doing it wrongly!” “Suggestion: Adjust your left shoulder, right shoulder and right angle properly”</p>
Ex3: Push-ups			<p>Correct form: “You’re on the right track”</p> <p>Incorrect form : “You’re doing it wrongly!” “Suggestion: Adjust your left elbow, left shoulder and right shoulder properly”</p>



Results : Qualitative

Excercise	Correct Form	Incorrect Form	Feedback/Suggestion
Ex4: Leg-abduction			<p>Correct form: “You’re on the right track”</p> <p>Incorrect form : “You’re doing it wrongly!” “Suggestion: Adjust your right elbow, right angle and left angle properly”</p>
Ex5: Lunge			<p>Correct form: “You’re on the right track”</p> <p>Incorrect form : “You’re doing it wrongly!” “Suggestion: Adjust your head, left shoulder and right angle properly”</p>
Ex6: Squats			<p>Correct form: “You’re on the right track”</p> <p>Incorrect form : “You’re doing it wrongly!” “Suggestion: Adjust your right wrist , right knee and right elbow properly”</p>



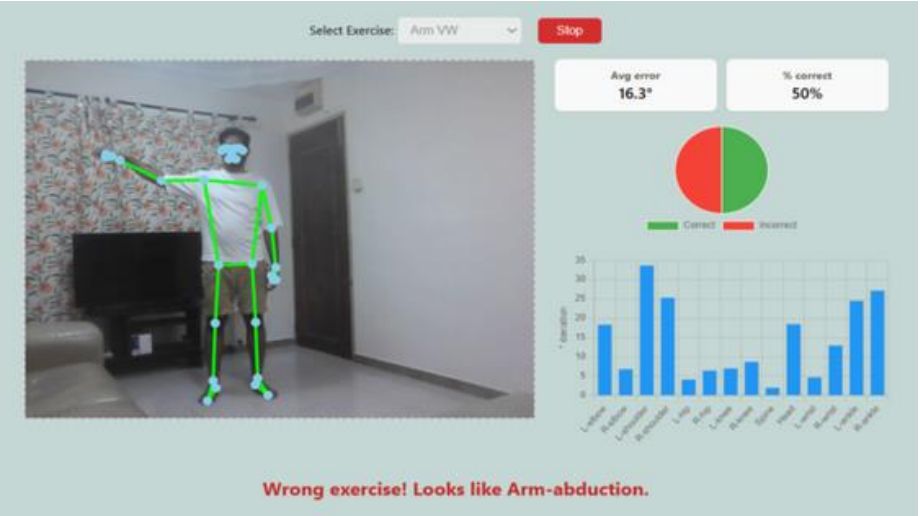
Results : Qualitative

Safety demo – “Wrong exercise” guard

Feedback/Suggestion

Exercise Selected:
Ex1: arm-abduction ”

Exercise Performed
Ex2: arm-VW”



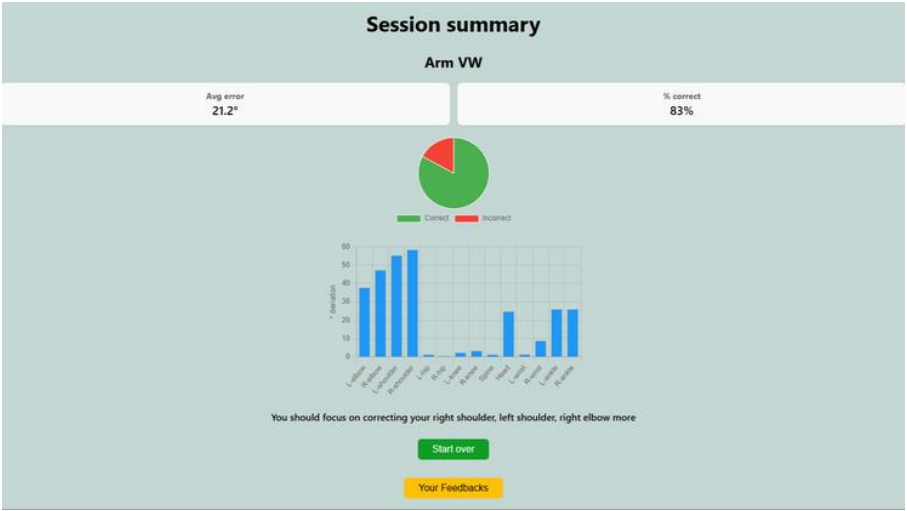
“Wrong exercise! Looks like arm-abduction ”



Session summary page

Advice

The pie chart, numeric tiles, and joint-error histogram from the session history, and an advice to guide the user



“You should focus on correcting your right shoulder, left shoulder, right elbow more”

Ablation Study:

Architecture Variants

Variant	Added Block(s)	Rep-F1	Ex-F1	MAE (°)	Δ Rep-F1	Δ MAE	FPS	Params
A	Baseline 1-D CNN only	0.797	0.993	8.49	–	–	9 160	0.25 M
B	+ Exercise embed (6 → 64 MLP)	0.819	0.994	6.18	↑ +2.2 pp	↓ -27 %	9 126	0.25 M
C	+ Bi-LSTM (2 × 256)	0.853	0.996	6.12	↑ +5.6 pp	↓ -28 %	7 256	3.40 M
FULL	B + C (embed + Bi-LSTM)	0.903	0.997	3.86	↑ +10.6 pp	↓ -55 %	7 383	3.41 M

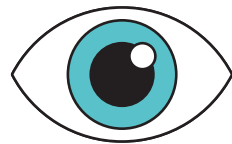
Which Blocks Really Pay Off?

- **Exercise context is cheap and valuable**
 - 0% extra params → +2pp Rep-F1 & – 2.3° MAE.
- **Temporal reasoning matters**
 - Bi-LSTM alone adds +5.6 pp Rep-F1 despite a 13× size jump.
- **Synergy, not mere addition**
 - Combining both cuts angular error in half (8.49 → 3.86°) and yields the largest quality gain, yet model still fits in ~ 11 MB.
- **Real-time preserved**
 - Even the full model sustains ≈30 FPS on CPU (7 k+ on GPU), meeting the live-feedback requirement.

Key Features: Live Feedback & Analytics

Visual feedback

- Landmarks color change– sky-blue by default; top-3 joints with $|\Delta\theta| \geq 8^\circ$ turn amber.
- Textual feedback display – green = good, red = bad form, amber = wrong exercise.
- suggestion (angle to to adjust) display in amber color



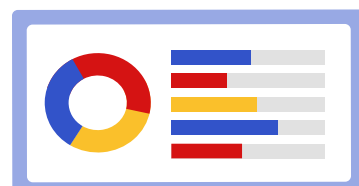
Spoken feedback

- Browser Speech-Synthesis speaks the same message; joint-level advice (e.g. “straighten left knee and right elbow”) has higher priority than generic banners.



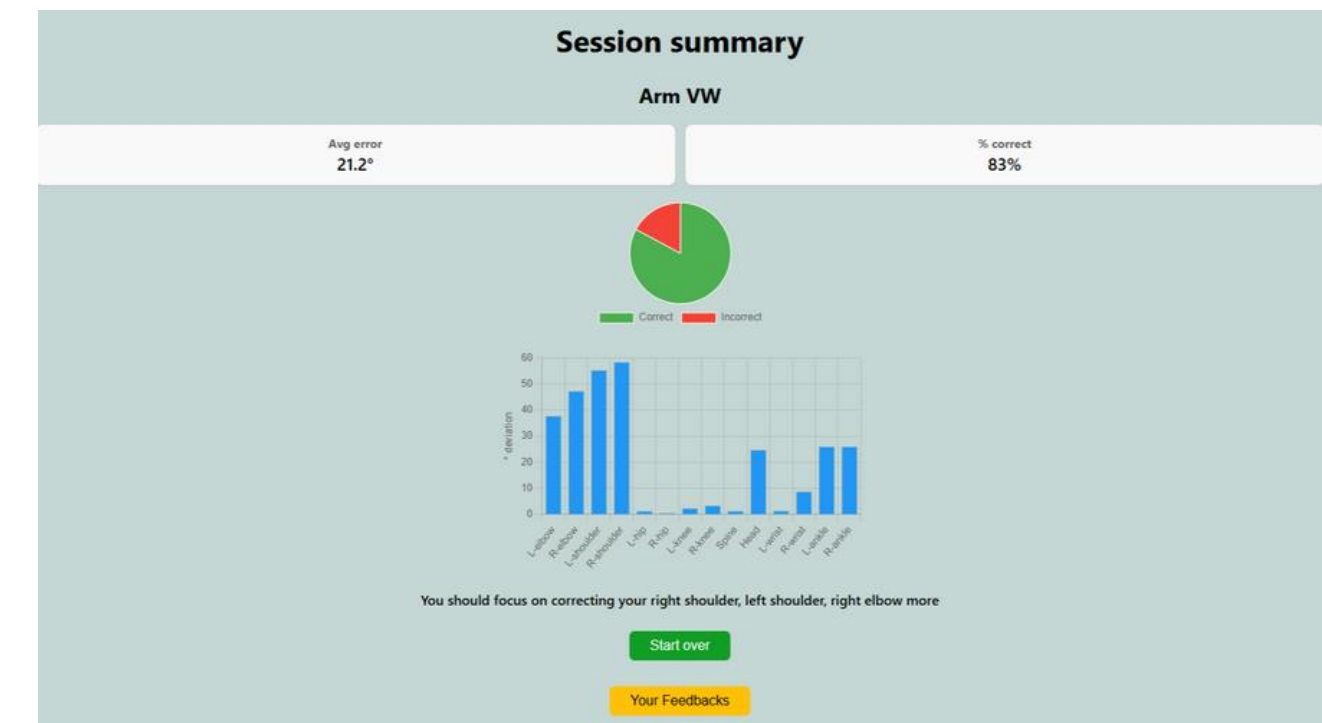
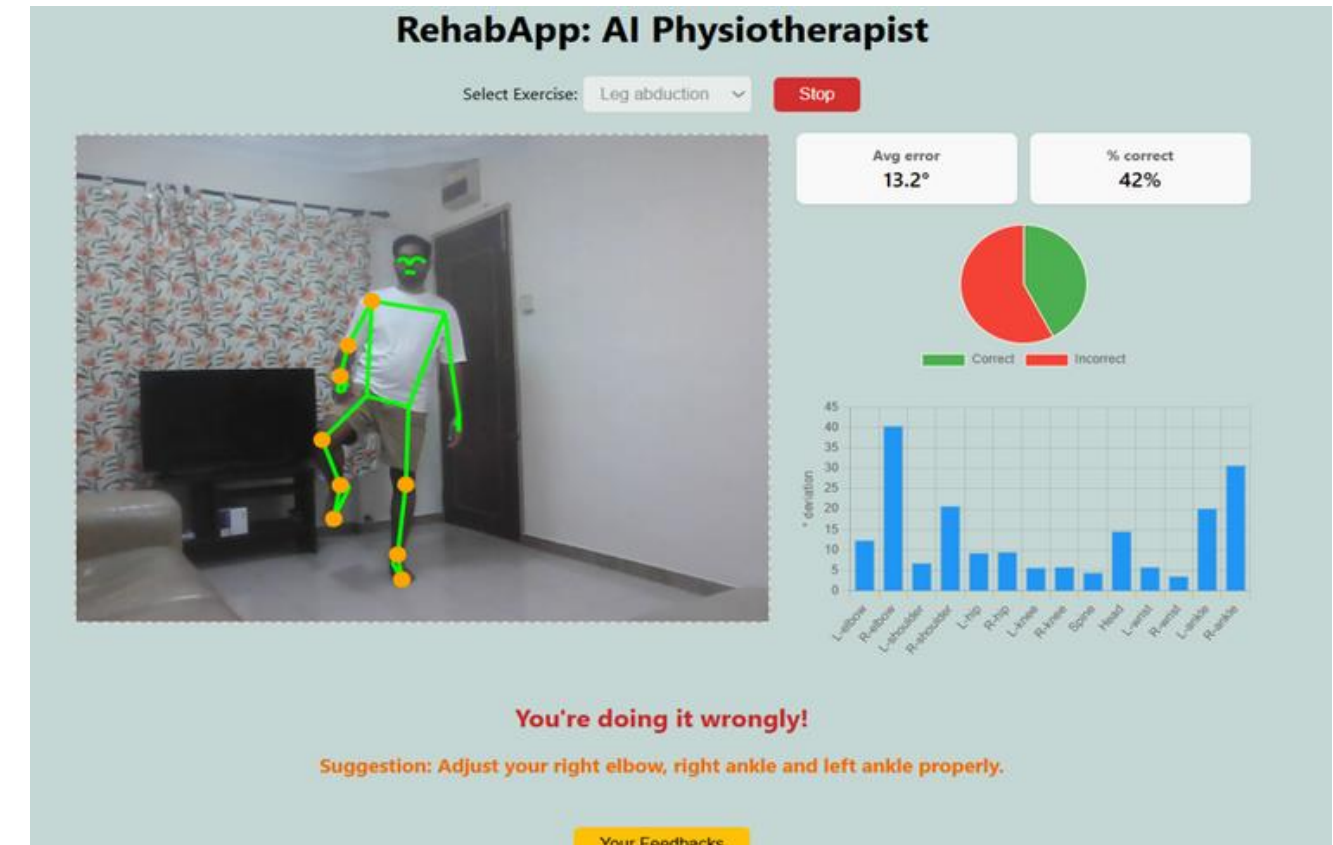
Real-time dashboard

- Updates every window (≈ 0.5 s):
- Pie chart correct / wrong
- Numeric tiles mean angle error, % correct
- 14-bin histogram of joint errors with the three worst joints called out.



Session summary

- Same charts from the real-time dashboard after the exercise end for the user to review and improve



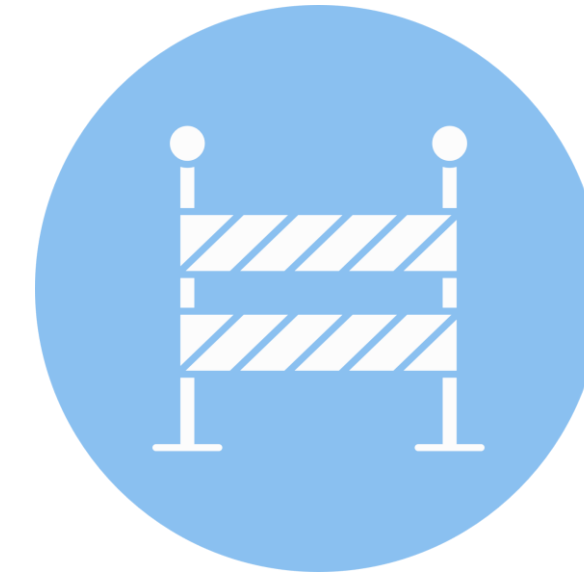
Limitations

Self-occlusion

When a limb is hidden (e.g. arms resting on thighs, crossed legs) MediaPipe drops landmarks, triggering spurious “bad-form” flags.

Camera-pose sensitivity

Accuracy degrades if the webcam is pitched or rolled by $> \pm 20^\circ$ or if lighting is uneven.

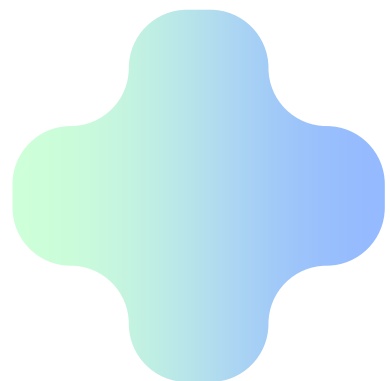


Scope constraints

Model was trained on 10 healthy young adults; it is untested on elderly, post-operative or high-BMI users (risk of domain shift).

Low-resolution extremities

Single-view, single-person, six drills, no on-device personalisation or multi-person support (yet).



Future Works

Robustness

- Add a lightweight self-supervised pre-text task to denoise landmarks under occlusion / harsh lighting.
- Fuse two camera views when available to recover hidden joints and improve 3-D angle accuracy.

Personalized Coaching

- 30-second calibration routine to learn each user's neutral joint baselines.
- Dynamic tolerance tightening as the patient improves, plus on-device few-shot fine-tuning.

Ultra-light Edge Deployment

- Quantise the model to 4-bit QAT ONNX and export as a cross-platform mobile SDK (Android / iOS / WebAssembly).
- Optimise CPU scheduling to keep real-time feedback while cutting battery drain.

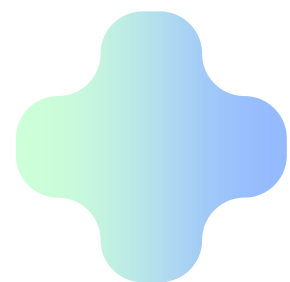
Clinical Validation

- Run a 6-week field study with post-operative patients ($n \approx 30$) vs. standard care; measure adherence, recovery time, and user satisfaction.
- Collect qualitative therapist feedback to refine cue phrasing.

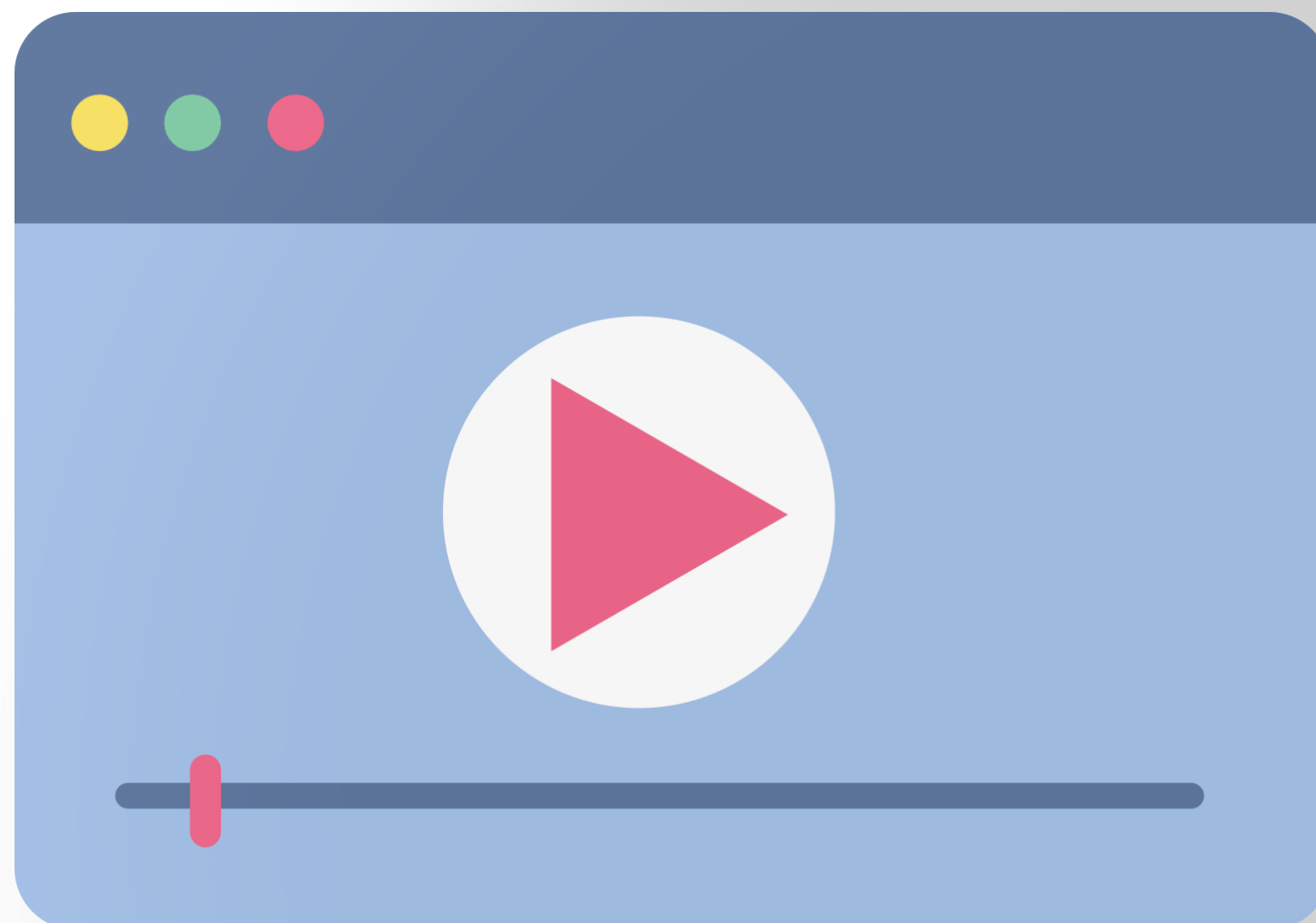
Feature Expansion

- Double the exercise library (e.g. balance drills, gait training) and introduce multi-person support.
- Add multi-language text-to-speech and haptic cues for broader accessibility.





System: Demo



References

[1] Faber, M., Andersen, M. H., Sevel, C., Thorborg, K., Bandholm, T., & Rathleff, M. The majority are not performing home-exercises correctly two weeks after their initial instruction—an assessor-blinded study. *PeerJ*, 3:e1102, 2015. DOI:10.7717/peerj.1102.

[2] A. Černek, J. Sedmidubsky, and P. Budíková, “REHAB24-6: Physical Therapy Dataset for Analyzing Pose Estimation Methods,” in **Proc. 17th Int. Conf. on Similarity Search and Applications* (SISAP)*, LNCS 14512, pp. 18–33, Oct. 2024, doi: 10.1007/978-3-031-75823-2_2.





T H A N K
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