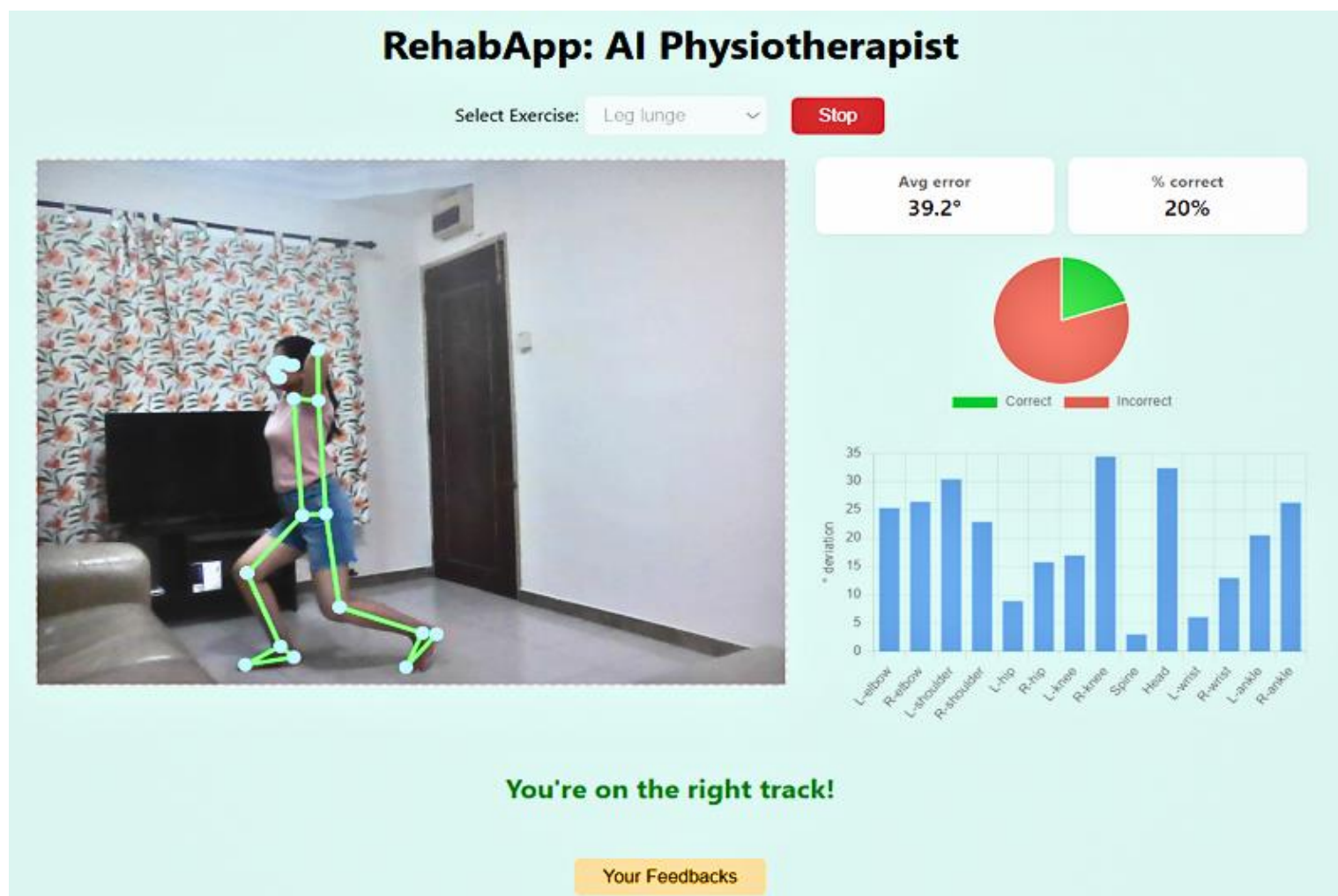


# Pose Correction System for Physical Therapy and Rehabilitation Using Computer Vision



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# Motivation: Why home Physical Therapy still needs a coach

## Widespread form errors

- 55% of patients perform  $\geq 1$  drill incorrectly <sup>1</sup>
- 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

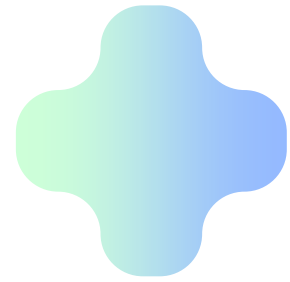
## Lightweight way forward

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



<sup>1</sup> Faber et al., PeerJ 2015 <sup>2</sup> 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: REHAB24-6<sup>2</sup>

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

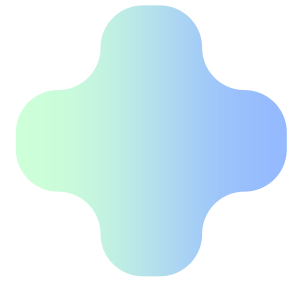
Exercise ID	Reps	Correct	Wrong	Frames
1	178	90	88	27 442
2	208	94	114	33 641
3	107	52	55	12 054
4	210	120	90	18 329
5	174	78	96	17 608
6	195	134	61	19 373
Total	1 072	568	504	128 447

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

Author-supplied frame-level segmentation

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



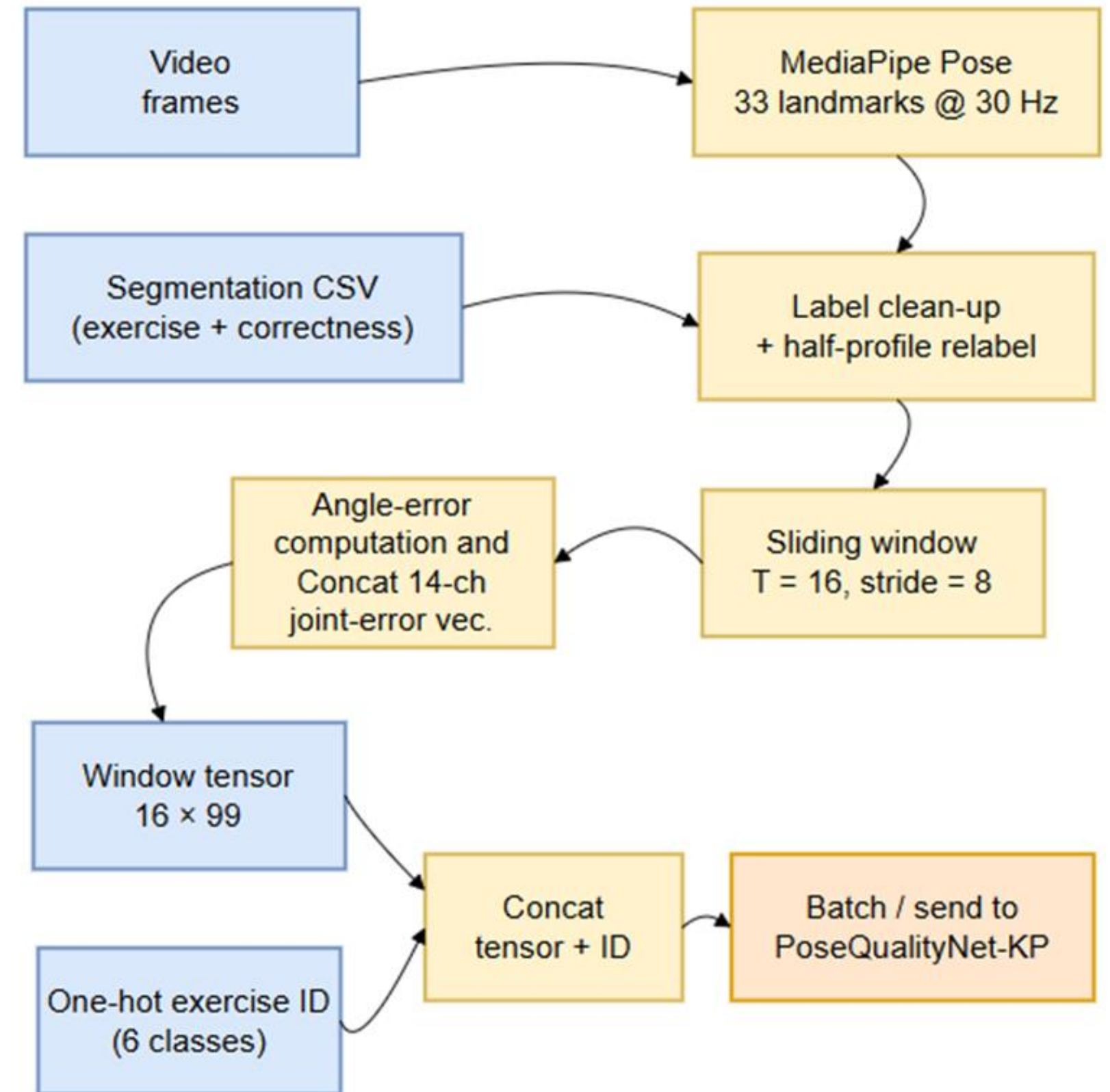
# Data: Augmentations and Pipeline

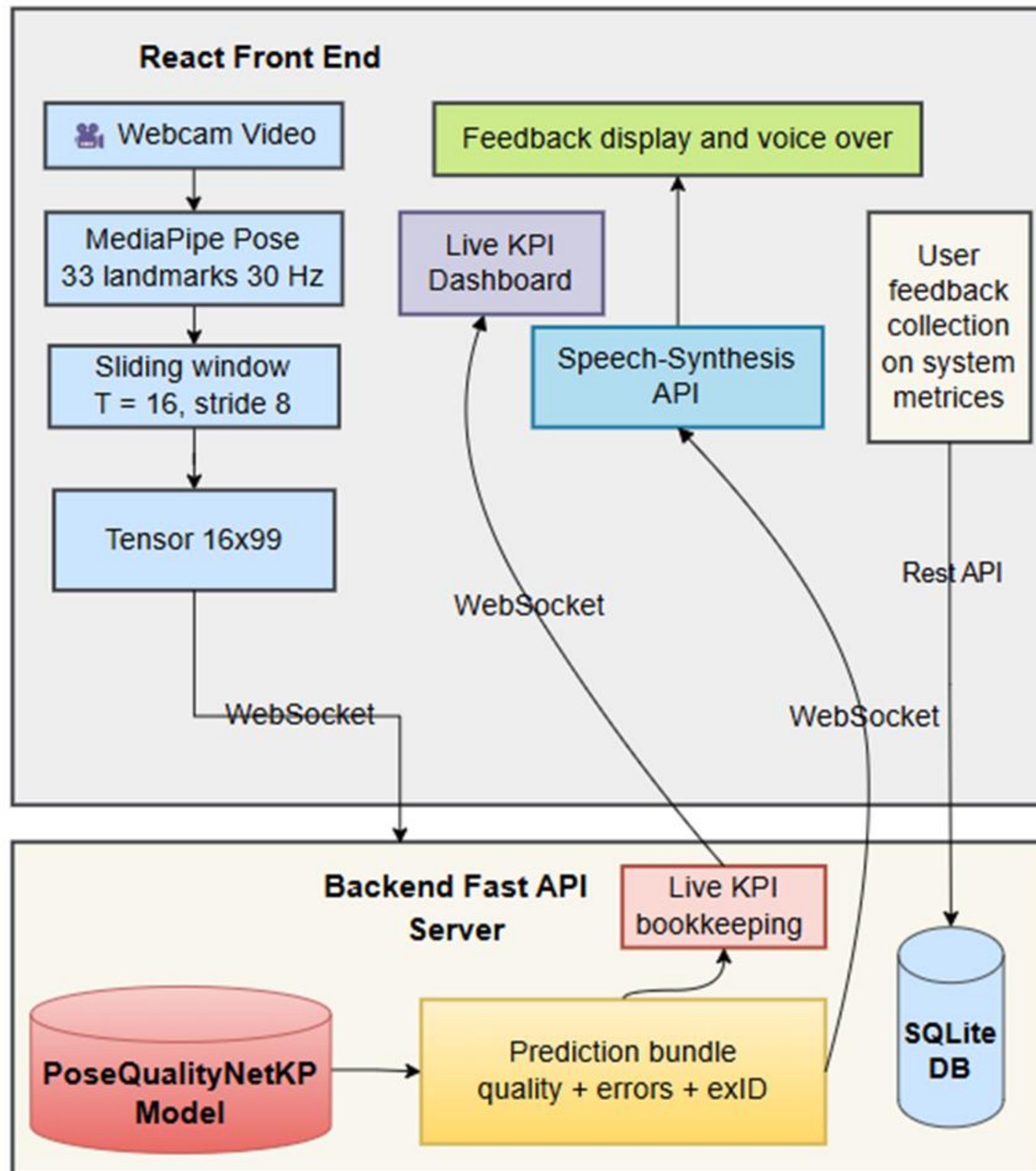
## Temporal & Label Augmentations

- 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

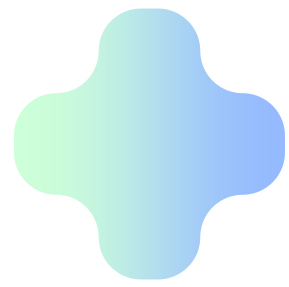
### Front-end (React, runs in browser)

- 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)

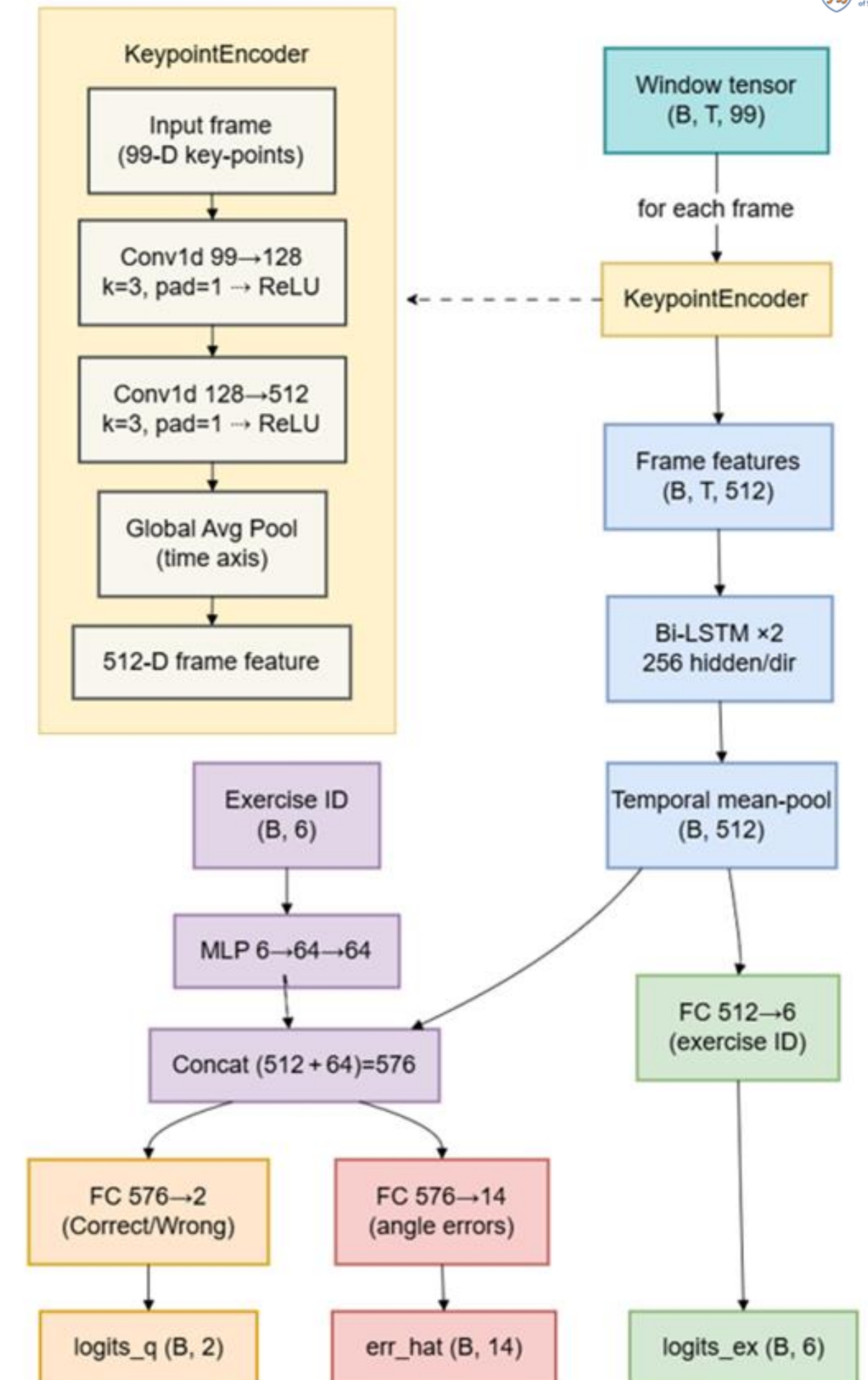
- Hosts PoseQualityNet-KP → predicts quality, 14 joint-angle errors & exercise ID in ≈ 2 ms
- Majority-vote buffer (5 windows) suppresses flicker; “wrong-exercise” guard blocks unsafe advice
- Sends compact JSON to front-end, logs KPIs & survey answers in SQLite (REST endpoint)



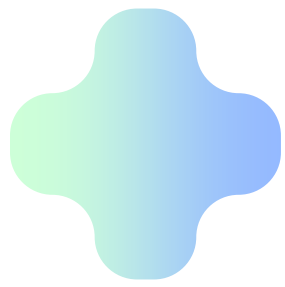


# Model Architecture: PoseQualityNet-KP

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

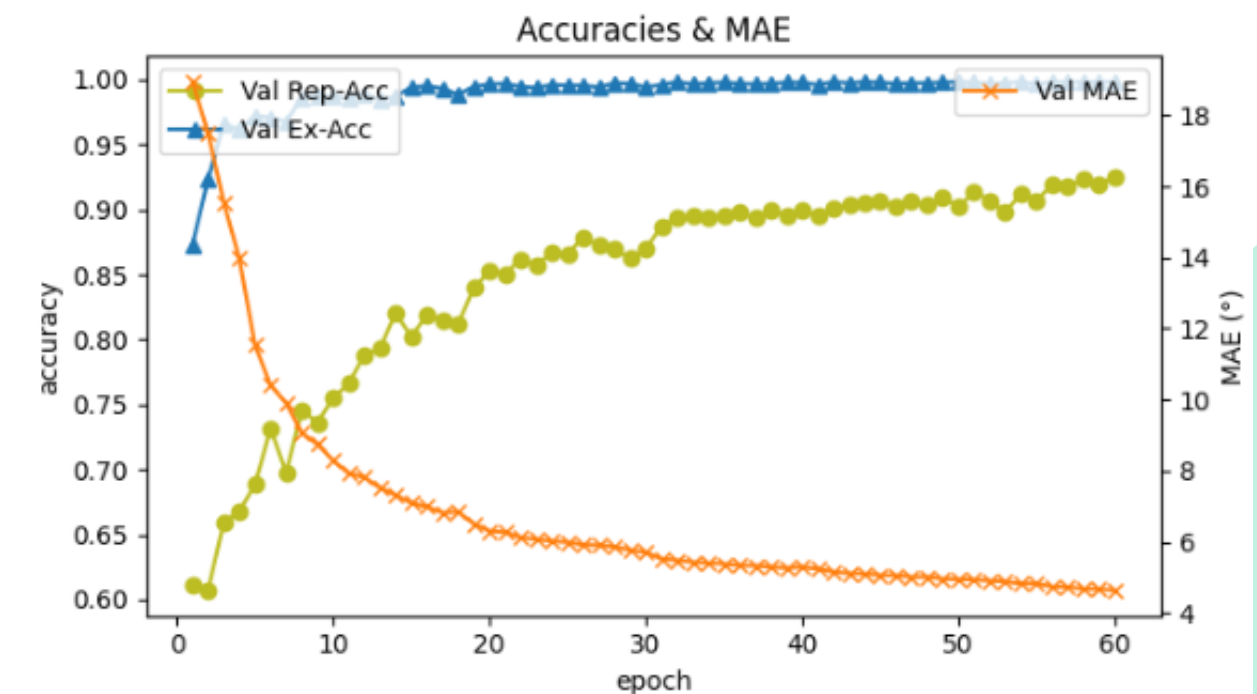
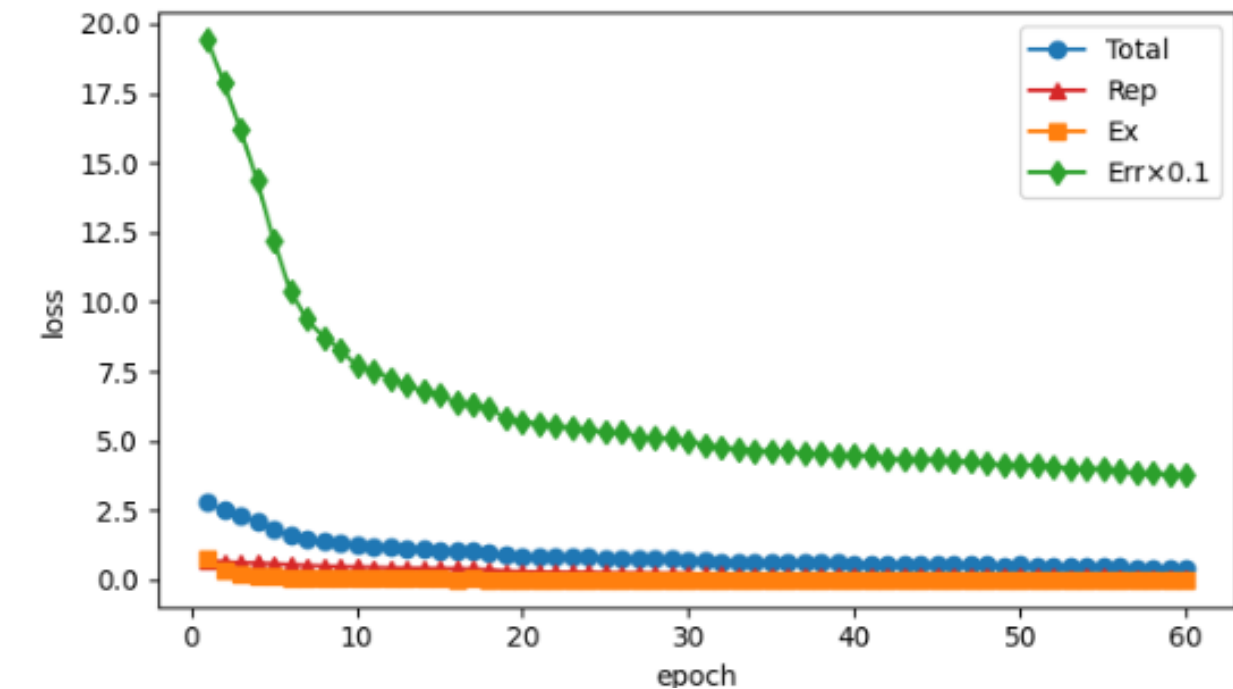
## Optimisation

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

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

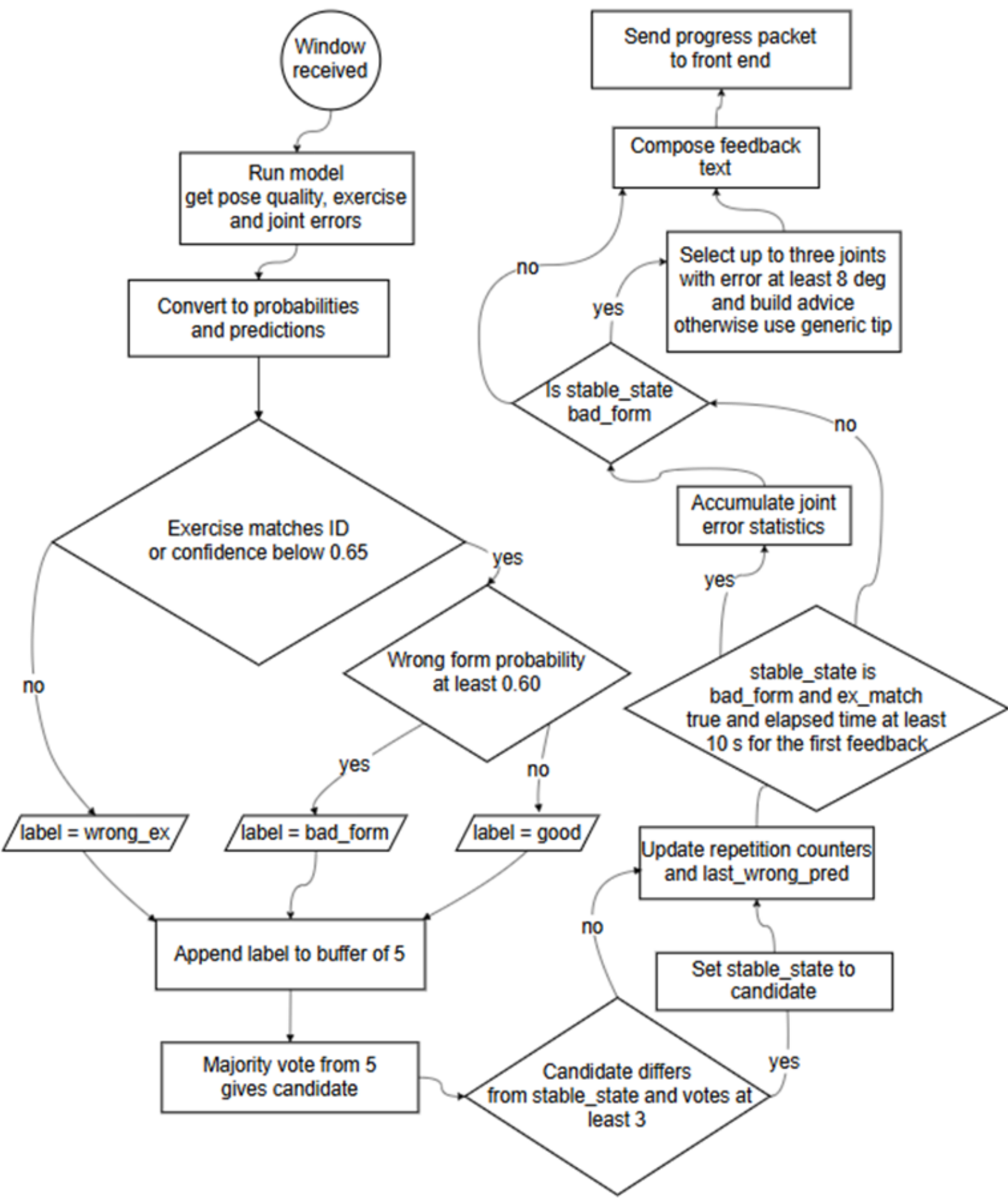
## Training time / hardware

- 30-35 epochs ( $\approx 40$  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	Feedback : “You’re on the right track!”  Suggestion : —	1. Quality head $\Rightarrow p(\text{wrong}) < 0.60$ and exercise ID agrees with the drop-down $\rightarrow$ state = good. 2. All joint errors $< 8^\circ \rightarrow$ corrections list is empty.
Bad form	Feedback : “You’re doing it wrongly!”  Suggestion (example): “Adjust your left hip, spine and right ankle properly.”	1 $p(\text{wrong}) \geq 0.60$ and exercise matches with selected $\rightarrow$ state = bad_form 2 Keep joints with $ \Delta\theta  \geq 8^\circ$ , sort by magnitude, take top 3 $\rightarrow$ e.g. {left-hip, spine, right-ankle}.
Wrong exercise	Feedback : “Wrong exercise! Looks like Push-ups.”  Suggestion : —	1 Exercise head $\neq$ selected and $\text{conf} \geq 0.65 \rightarrow$ state = wrong_ex 2 Skip joint-error logic entirely.



# 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

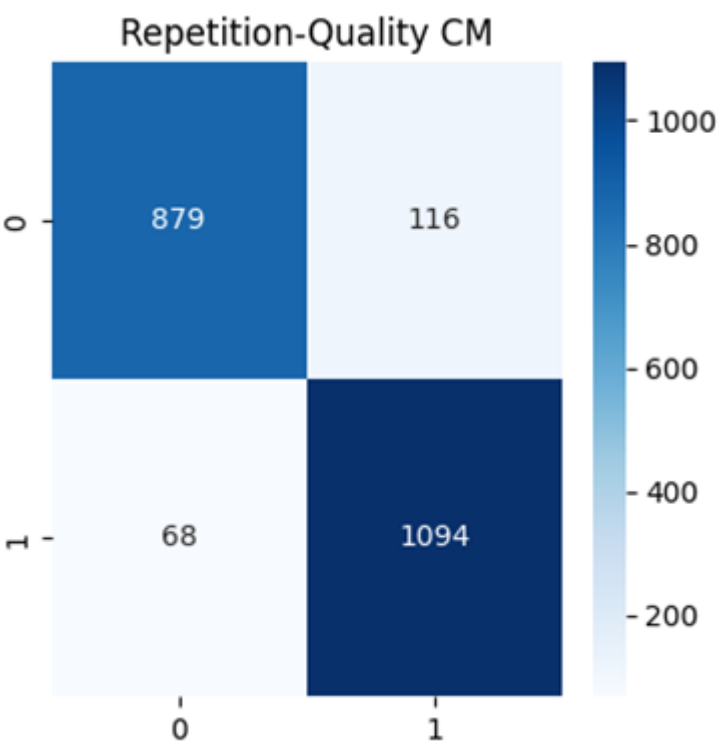
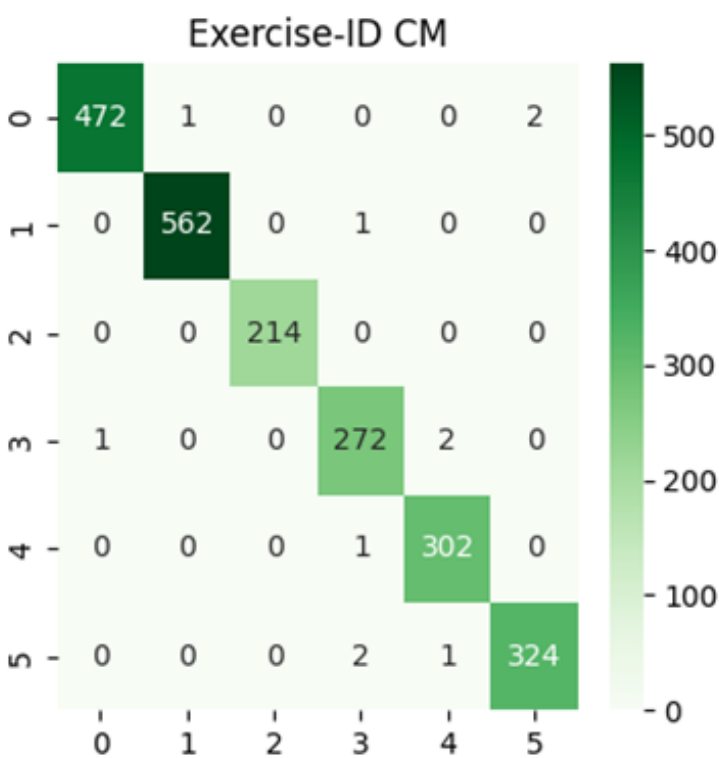
- 7500 windows s<sup>-1</sup> ≈ 30 fps end-to-end on mid-range CPU
- 3.41M parameters (< 13MB), no GPU required
- Latency: ≈ 2.5 ms (browser → server → browser)

## 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

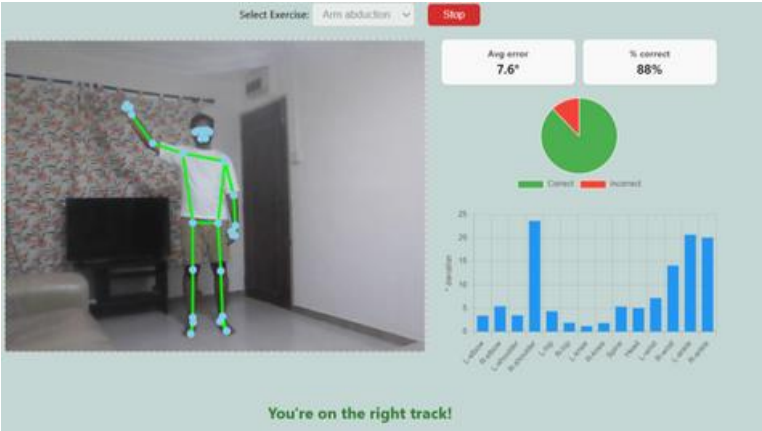
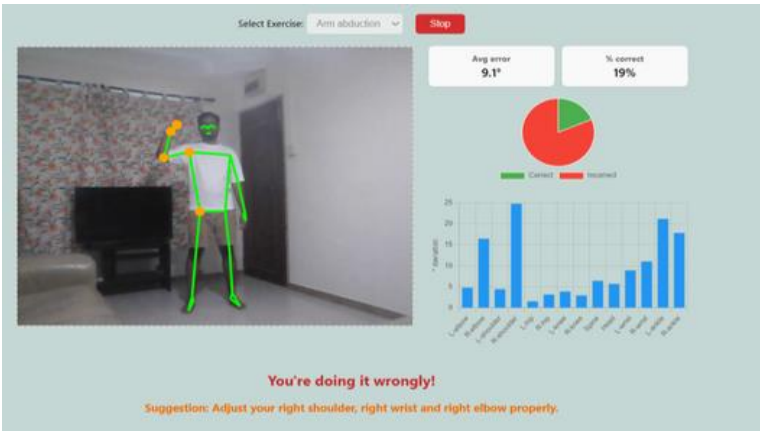
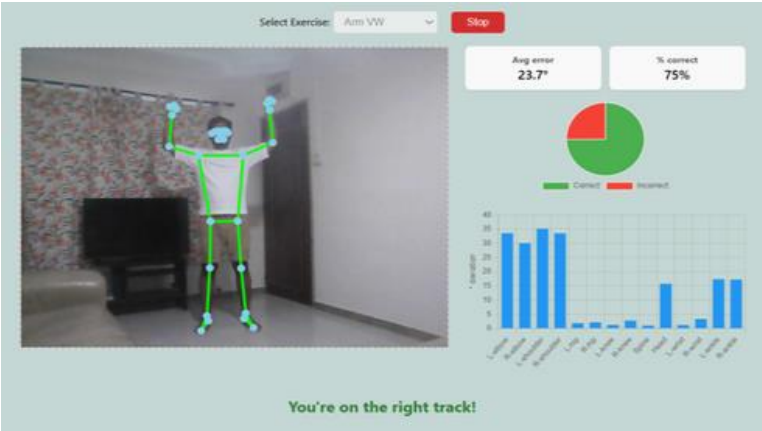

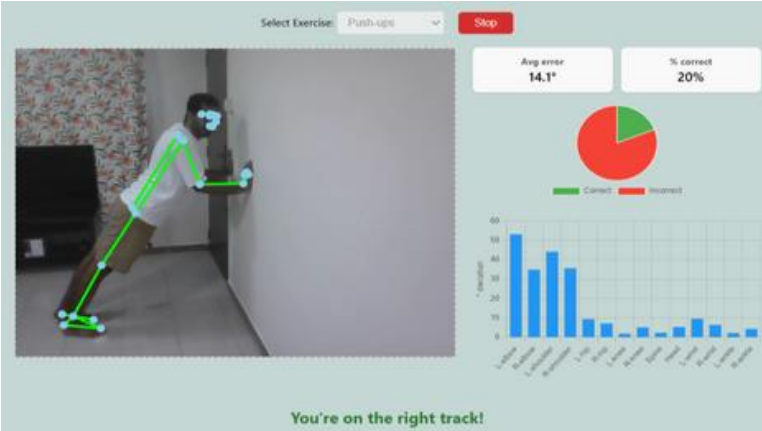

- Mobile-ready: real-time, <13 MB, runs on-device
- Rich feedback: joint-level errors + wrong-exercise guard
- State-of-the-art accuracy on six diverse rehab drills



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

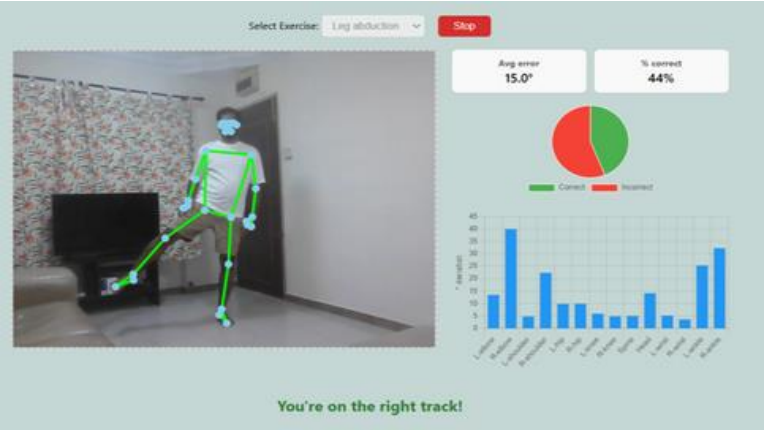

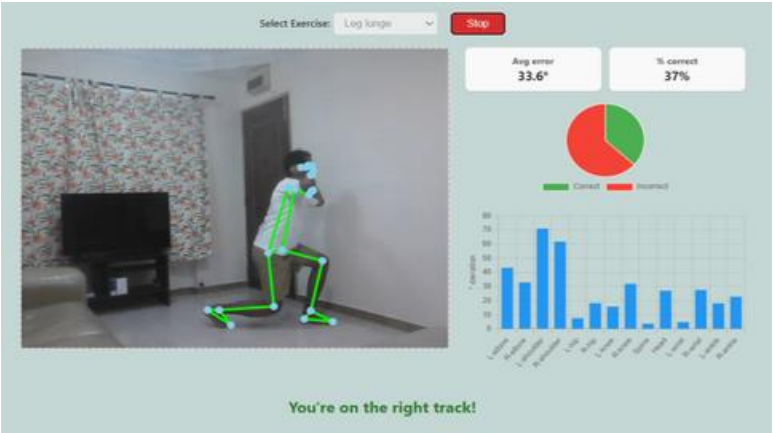
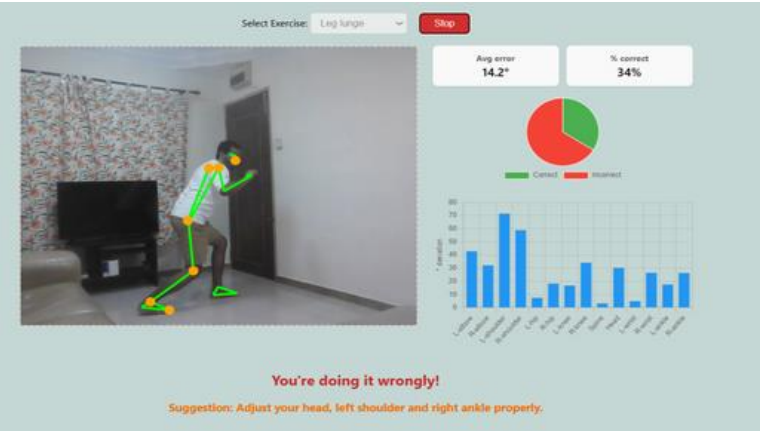
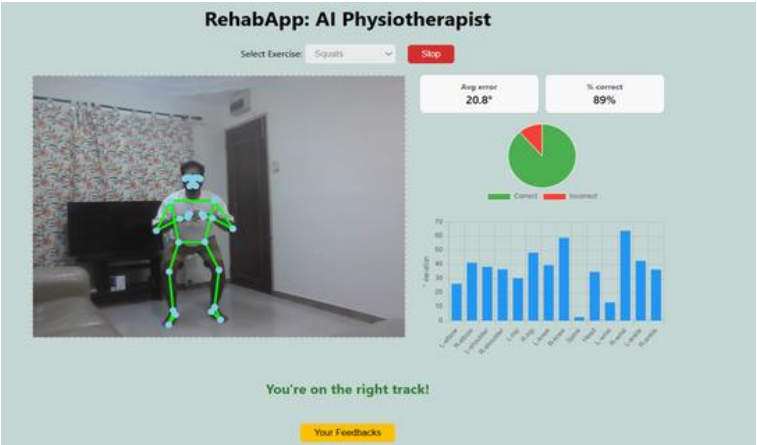
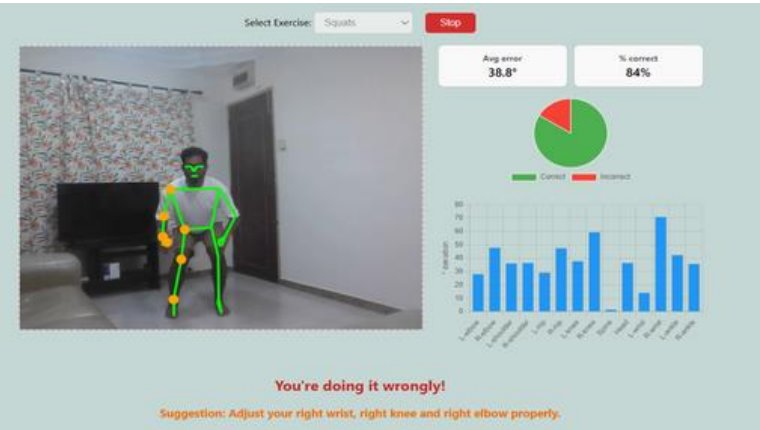


# Results : Qualitative

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>





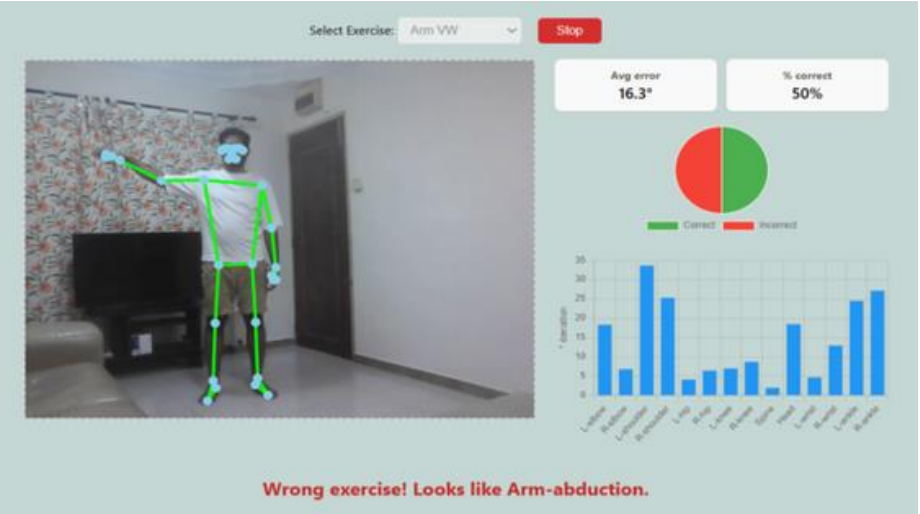
# Results : Qualitative

## Safety demo – “Wrong exercise” guard

## Feedback/Suggestion

Exercise Selected:  
Ex1: arm-abduction ”

Exercise Performed  
Ex2: arm-VW”



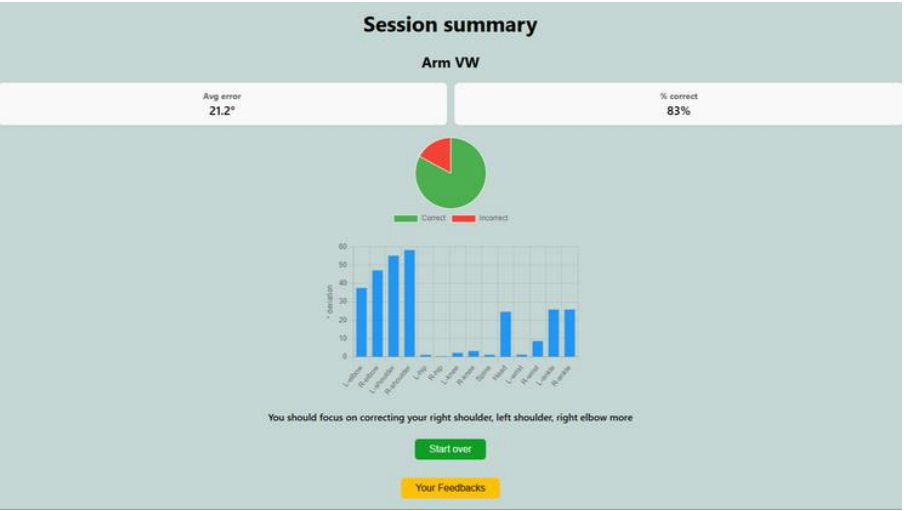
“Wrong exercise! Looks like  
arm-abduction ”



## 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
<b>A</b>	<b>Baseline</b> 1-D CNN only	0.797	0.993	8.49	–	–	<b>9 160</b>	<b>0.25 M</b>
<b>B</b>	+ <b>Exercise embed</b> (6 → 64 MLP)	0.819	0.994	6.18	↑ +2.2 pp	↓ -27 %	9 126	0.25 M
<b>C</b>	+ <b>Bi-LSTM</b> (2 × 256)	0.853	0.996	6.12	↑ +5.6 pp	↓ -28 %	7 256	3.40 M
<b>FULL</b>	<b>B + C</b> (embed + Bi-LSTM)	<b>0.903</b>	<b>0.997</b>	<b>3.86</b>	↑ +10.6 pp	↓ -55 %	7 383	3.41 M

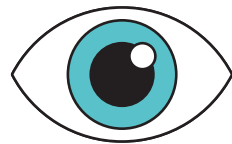
### Which Blocks Really Pay Off?

- **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 ~ 13 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



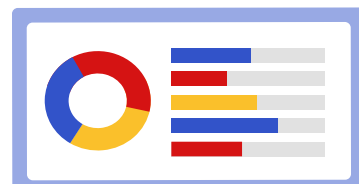
## Spoken feedback

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



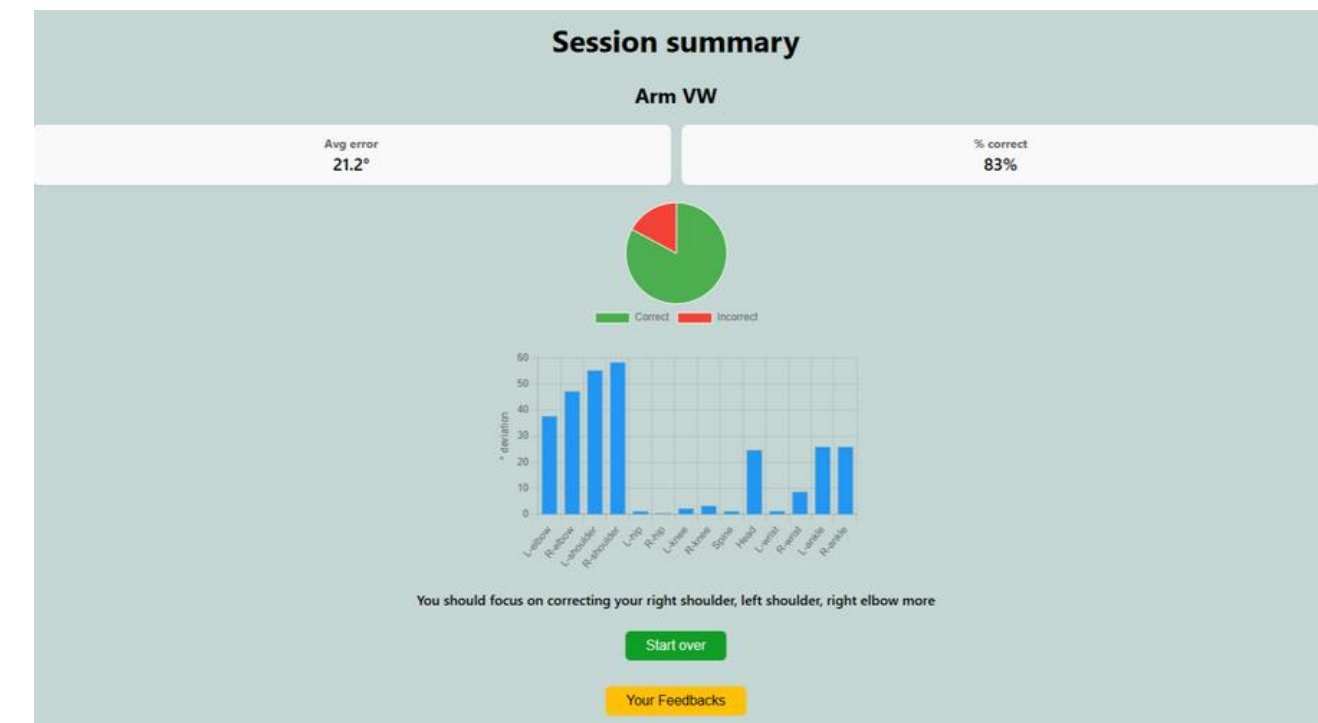
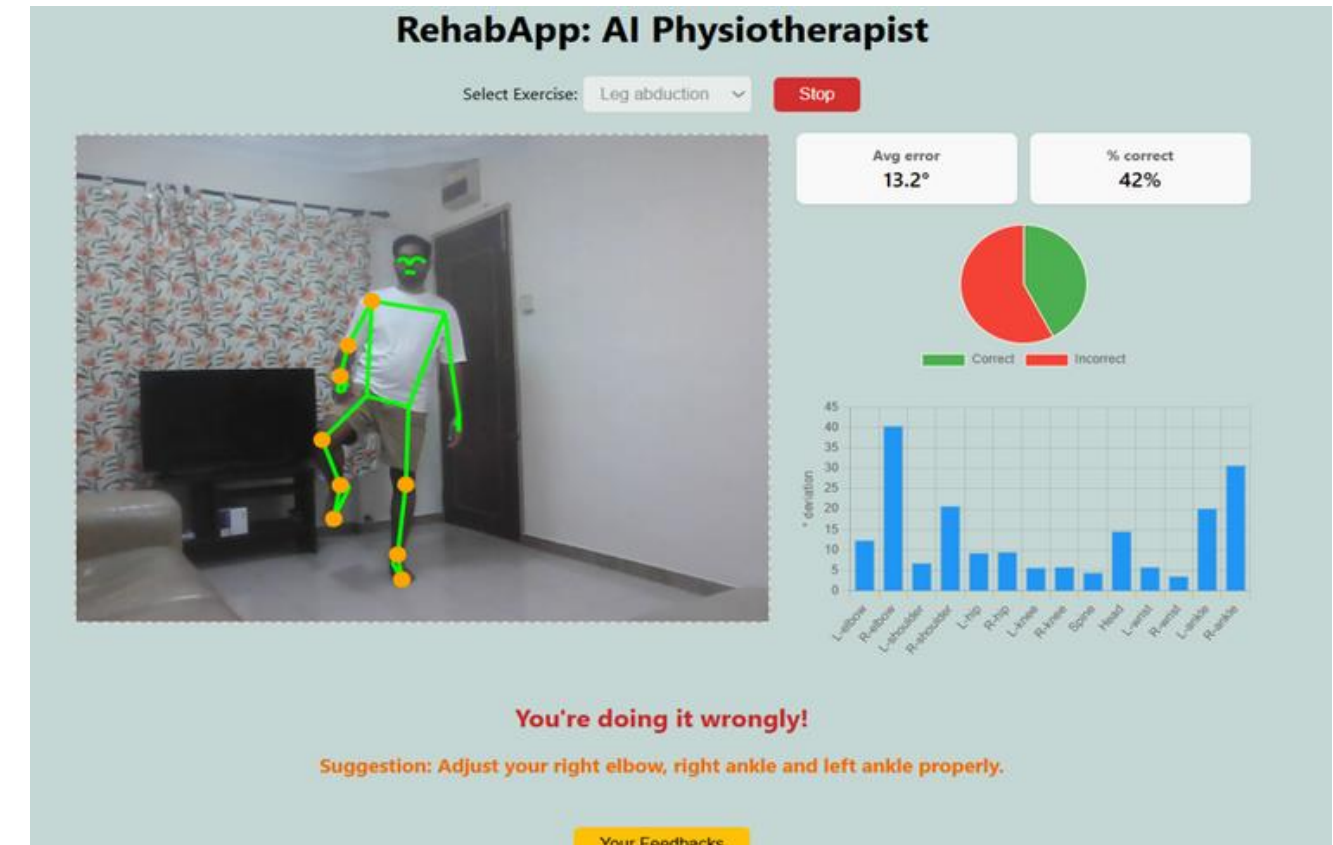
## Real-time dashboard

- Updates every window ( $\approx 0.5$  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



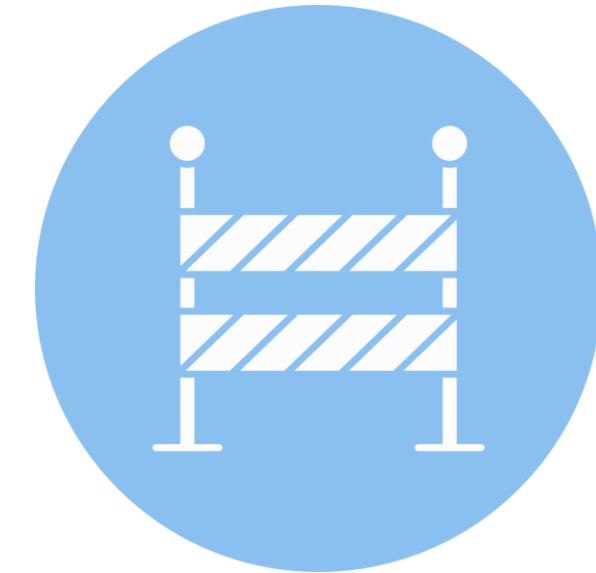
# Limitations

## 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.

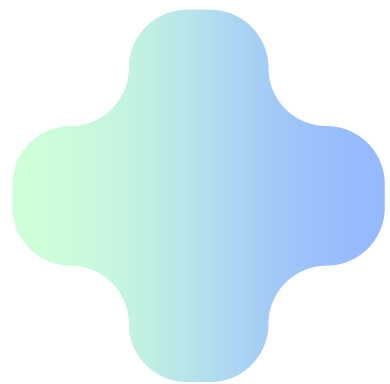


## Scope constraints

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.

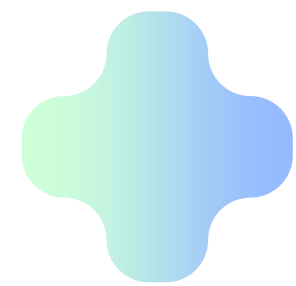
## Clinical Validation

- 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.

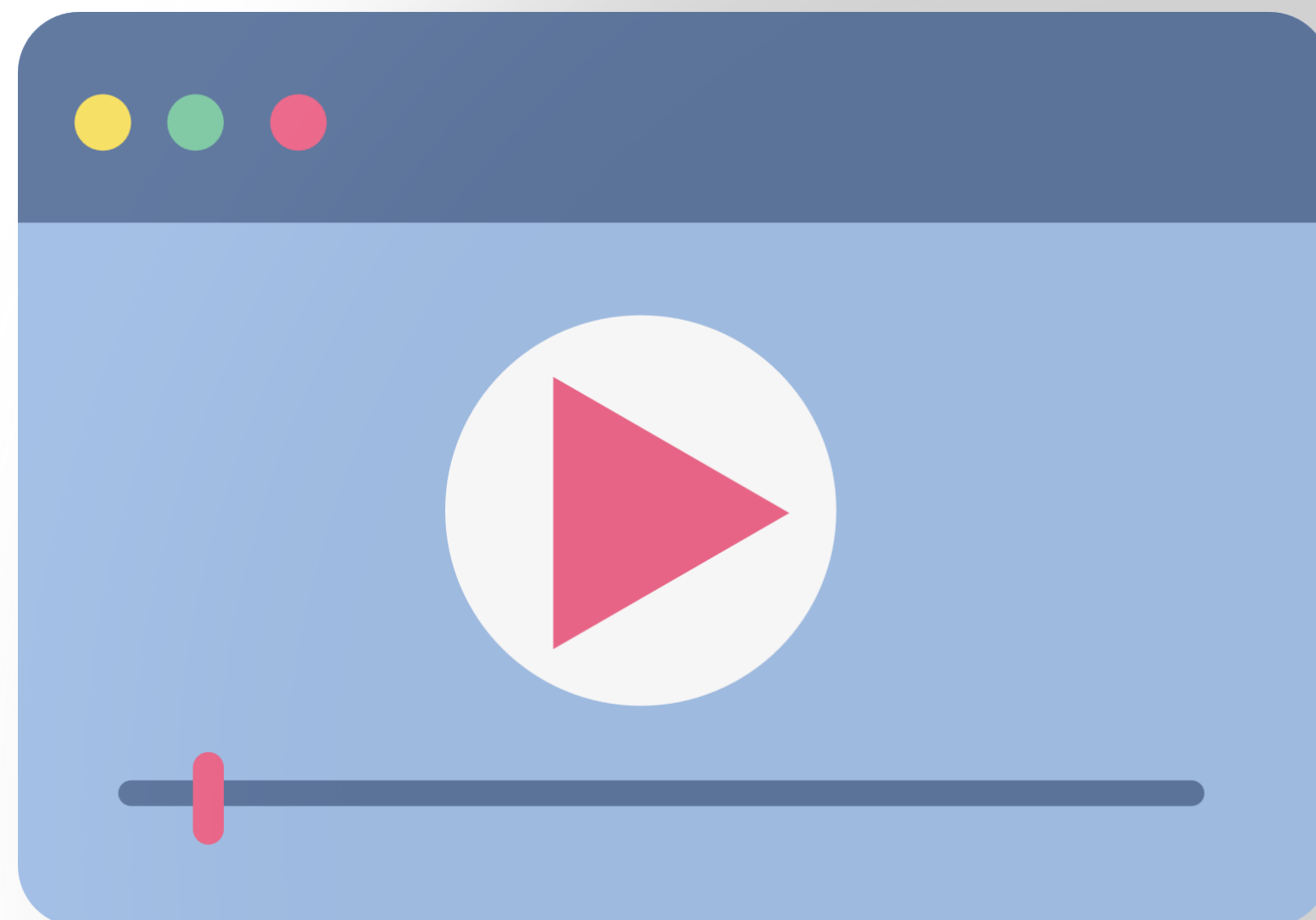
## Feature Expansion

- 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**  
**Y O U**

