HRV Coach Pro v2.1

Autonomous Clinical Intelligence

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Project Overview

- **HRV Coach Pro v2.1**: An autonomous agentic system for clinical HRV analysis.
- **Core Function**: Converts raw noisy ECG → validated HRV metrics → clinical-style insights.
- **Agentic Approach**: Utilizes a self-correcting workflow to adapt to signal quality.
- **Goal**: Provide scalable, reliable HRV analysis without requiring expert manual intervention.

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The Signal-to-Insight Gap

- **The Pipeline**: ECG → R-peaks detection → RR Intervals → HRV Metrics.
- **The Challenges**: Noise, baseline drift, motion artifacts, and EMG interference often cause detection failure.
- **The Risk**: Incorrect peak detection leads to invalid RR intervals and distorted HRV results.
- **Interpretation**: Standard metrics (RMSSD, SDNN) are difficult for non-experts to understand without context.

Agentic Workflow & Architecture

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Sense → Decide → Act → Verify

- **Data Ingestion**: PhysioNet + CSV support.
- **Signal Processing**: Filtering, peak detection, and RR calculation.
- **Strategy Control**: Validation-driven feedback loop.

Hybrid Intelligence

- **Deterministic**: NeuroKit2 & SciPy for signal processing.
- **Probabilistic**: DeepSeek V3.2 for metric interpretation.
- **Safety**: Separation of computation vs. interpretation.

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Strategy Pattern: Why Multiple Pipelines?

- **Adaptability**: A single pipeline fails across different signal conditions.
- **Strategy Library**:
  - **Strategy A**: Standard filtering for clean clinical-grade ECG.
  - **Strategy B**: Aggressive filtering for noisy wearable data.
  - **Strategy D**: Localized handling for 50 Hz power-line interference.
- **Selection**: The agent tests strategies and selects the best one based on a validation grade.

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Decision Loop & Validation Logic

1. **Sensing**: Checks for baseline wander, high-frequency noise, and sampling consistency.
2. **Decision**: Try Strategy A $\rightarrow$ Detect Peaks $\rightarrow$ Validate results.
3. **Backtracking**: If Grade is "C" or "Reject", switch to Strategy B or D.
4. **Criteria**: Physiological HR range, RR consistency, and outlier artifact rejection.
5. **Output**: Only accept results that pass physiological plausibility.

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Challenges & Results

- **NumPy 2.0 Compatibility**: Fixed breaking changes in NeuroKit2 by implementing a compatibility shim for `trapezoid`.
- **Local Data**: Resolved 50 Hz noise issues via Strategy D and timestamp-based sampling inference.
- **Key Deliverables**:
  - Clean ECG plots with labeled R-peaks.
  - Signal quality grading and HRV summary.
  - Downloadable PDF reports with LLM-generated interpretations.

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Future Work

- Integration of local LLM models to enhance data privacy.
- Real-time edge deployment for continuous health monitoring.
- Expansion of the strategy library to support more diverse sensor types.

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Team Contribution

Member	Contribution	Responsibilities
Khan	40%	Code Development, Video Recording
Liu	30%	Documentation, Hosting Meeting
Peng	30%	Video Editing, Slide Creation