Driver Drowsiness Detection System

ECG-based Fatigue Analysis with Multi-Agent AI Architecture

Wei, JungYing Wu, KunChe Zheng, YiKai
National Cheng Kung University

Agentic AI Course – Spring 2026

NORDLING LAB

Outline

1. Problem & Motivation
2. System Architecture
3. Demo & Results
4. Challenges & Lessons Learned
5. Conclusion

Problem Statement

Driver Fatigue: A Critical Safety Issue

- Driver fatigue causes **thousands of accidents** globally each year
- Alert-to-drowsy transition is **invisible** to the driver
- Delayed reaction time and impaired decision-making
- Current solutions have significant limitations:
  - Camera-based: Fails in poor lighting
  - Steering-based: Detects too late

NORDLING LAB

Our Solution: ECG-based Detection

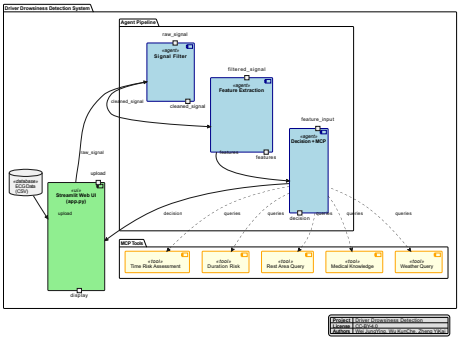
Why ECG?

- **Physiological indicator**: Directly measures autonomic nervous system activity
- **Continuous monitoring**: Non-invasive, works in all conditions
- **Early detection**: Changes in HR and HRV precede behavioral signs

Key Physiological Markers:

Metric	Alert State	Drowsy State
Heart Rate (HR)	Higher (70-80 bpm)	Lower (55-65 bpm)
HRV (SDNN)	Lower (30-50 ms)	Higher (70-100 ms)

Three-Agent Agentic AI Architecture



Agent 1 - Signal Filter:

- Bandpass filter (0.5-40 Hz)
- Notch filter, Normalization

Agent 2 - Feature Extraction:

- R-peak detection
- HR, HRV metrics (SDNN, RMSSD)

Agent 3 - Decision + MCP:

- Multi-factor risk scoring
- MCP tool queries

NORDLING LAB

MCP Tool Integration for Contextual Awareness

Model Context Protocol (MCP) Tools

Agent 3 queries multiple contextual factors:

Environmental Context

- **Weather Query**: Hot/humid $\rightarrow$ higher fatigue
- **Time Risk**: 02:00-05:00 = Very High risk
- **Rest Areas**: Nearest rest stops

Driver Context

- **Driving Duration**: $>$2 hours = High risk
- **Medical KB**: HRV interpretation
- **Personal Baseline**: Individual variation

Multi-modal integration for more accurate drowsiness detection

Risk Scoring System

Multi-Factor Risk Assessment

Risk Factor	Max Score
Low Heart Rate ($<$60 bpm)	30
High HRV (SDNN $>$ 80 ms)	35
Baseline Deviation	15
Time Risk (late night)	40
Weather Factors (hot/humid)	15
Driving Duration ($>$3 hours)	40
Maximum Total	**175**

Risk Levels: Low (0-29) | Medium (30-49) | High (50-69) | Very High (70+)

NORDLING LAB

Test Results

Validation with Synthetic ECG Data

Test Data	Expected	Actual	Status
ecg_normal.csv	Low Risk	Low Risk	PASS
ecg_drowsy.csv	High Risk	Very High	PASS
ecg_long_drowsy.csv	Very High	Very High	PASS

Performance Metrics:

- Test suite: **25 tests, 100% pass rate**
- Processing time: $<$**1 second** for 30-second recording
- Pipeline latency: $<$**2 seconds** end-to-end

System Interface

Streamlit Web Application

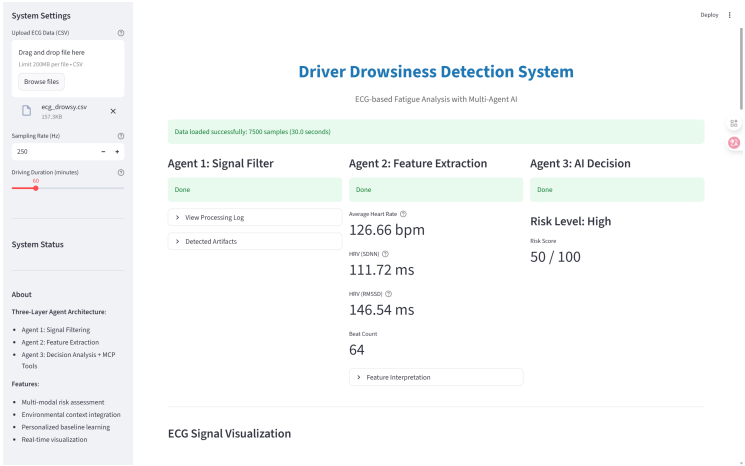


Figure: Real-time driver fatigue monitoring dashboard

NORDLING LAB

Challenges & Solutions

Technical Challenges:

1. **Motion Artifacts**
   - Solution: Multi-stage filtering
2. **Individual Variation**
   - Solution: Personalized baseline
3. **Real-time Processing**
   - Solution: Efficient signal processing

Lessons Learned:

1. **Agent modularity** enables independent testing and improvement
2. **MCP tools** provide valuable context beyond physiological data
3. **Rule-based decisions** can be effective without API costs

NORDLING LAB

Agentic AI vs Chat-based Approach

Aspect	Agentic AI	Chat-based
Processing Time	1-2 seconds	30-45 minutes
Manual Steps	1 (upload file)	10+ steps
Error Rate	0% (automated)	Higher (manual)
Reproducibility	100%	Variable
Real-time Capable	Yes	No

Key Insight: Agentic AI excels at **repetitive, multi-step workflows** with clear structure. Chat-based AI is better for **exploratory, one-off questions**.

NORDLING LAB

Conclusion

Summary:

- Built a **three-agent pipeline** for ECG-based drowsiness detection
- Integrated **MCP tools** for multi-modal context awareness
- Achieved **100% test pass rate** with $<$2s processing time
- Demonstrated clear advantages over chat-based approaches

Future Work:

- Integrate real weather API and GPS location
- Validate with real ECG data from driving studies
- Add real-time streaming support

Thank you! Questions?

Code: `project-code-group/2026-Wei-Wu-Zheng/`