Temporal Modeling of Heart Rate Variability for Driver Drowsiness Detection using LSTM

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Motivation

- **Driver drowsiness** is a major cause of road accidents
- Early drowsiness detection leads to safer roads
- **Physiological signals** can detect fatigue earlier than behavior or vehicle data

Objective

Develop a **data-driven model** to detect driver drowsiness using:

- Heart Rate Variability (HRV)
- Temporal deep learning (LSTM)

Dataset

- 20 participants (real-road motorway driving)
- Conditions:
  - Alert (afternoon)
  - Sleep-deprived (after midnight)
- ECG recorded at 256 Hz
- Drowsiness labeled using Karolinska Sleepiness Scale (KSS)

Methodology

- Signal Processing:
  - ECG -> R-peak detection (Pan-Tompkins)
  - Extract Inter-Beat Intervals (IBIs)
  - Sliding windows:
    - 2-minute segments
    - 50% overlap
- Feature Extraction:
  - Time-domain (e.g., SDNN)
  - Frequency-domain (LF, HF, LF/HF)
  - Nonlinear (SD1, SD2)
- Model Architecture:
  - Single-layer LSTM
  - Followed by Fully Connected Layer
  - Output: Binary classification
    - Alert
    - Drowsy (KSS ≥ 7)

Evaluation

- Strategies:
  - 10-Fold Cross-Validation
  - Leave-One-Subject-Out (LOSO)
- Metrics:
  - Accuracy
  - Sensitivity
  - Specificity
  - F1-score

Insights

- HRV contains meaningful drowsiness signals
- Temporal modeling (LSTM) is effective
- BUT:
  - Models struggle across unseen subjects
  - Personalization is likely necessary

Future Work

- Multimodal data fusion:
  - EEG, EOG, driving behavior
- Personalized / adaptive models
- Larger and more balanced datasets

Key Findings

- Strong performance in cross-validation
- Significant drop in LOSO → generalization challenge
- High variability between individuals
- Class imbalance impacts results

Conclusion

- HRV + LSTM is a promising, non-intrusive approach
- Real-world deployment requires:
  - Better generalization
  - Hybrid modeling strategies

Table 1. Classification Performance (mean±std)

Metric	10-Fold CV	LOSO
Accuracy	0.878 ± 0.017	0.610 ± 0.169
Sensitivity	0.821 ± 0.030	0.427 ± 0.300
Specificity	0.913 ± 0.026	0.671 ± 0.298
F1-score	0.837 ± 0.021	0.379 ± 0.257

Figure 1. Example confusion matrix obtained from 10-fold cross-validation

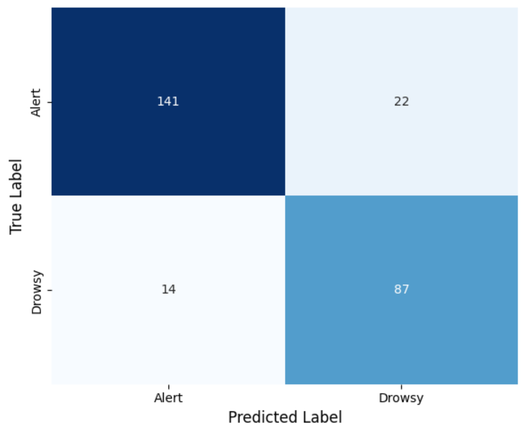
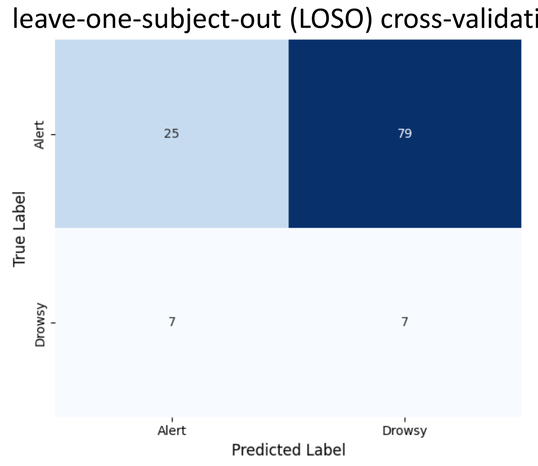
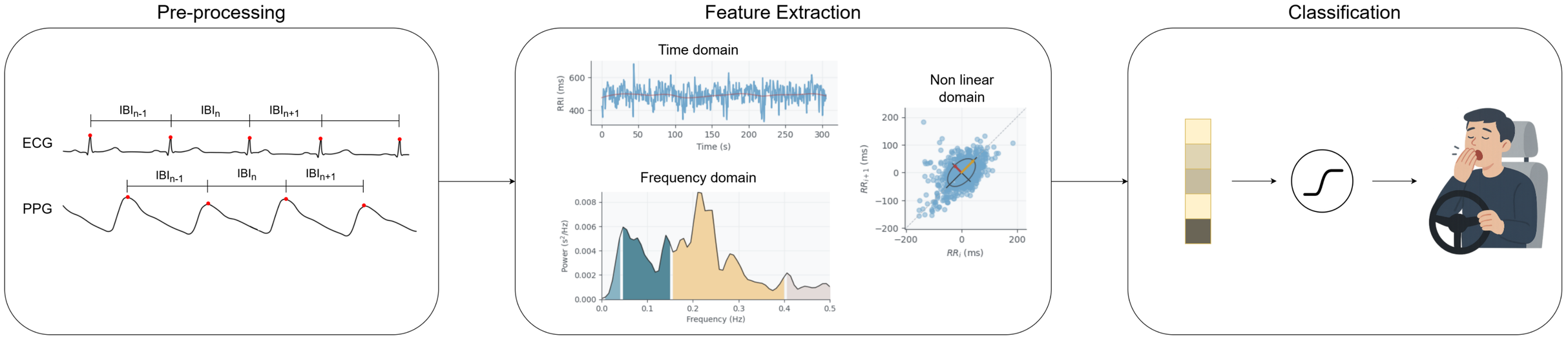


Figure 2. Example confusion matrix obtained from leave-one-subject-out (LOSO) cross-validation





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