



Integrated Data Analytics for Wire Bonding Processes in Smart Power Module Production

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1. Motivation and Industrial Context of Wire Bonding Processes

- Key manufacturing step for power modules, directly influencing reliability, lifetime, and functional safety
- Highly sensitive to material variability, tool wear, and environmental conditions
- State-of-the-art quality control is often based on machine-dependent, vendor-specific dashboards and offline testing [1, 2] → Limitation in cross-machine correlation, factory-level transparency, and system process control

2. Objectives and Contributions

- Operationalization of data analytics for wire bonding in an industrial production environment
- Standardization of data acquisition across heterogeneous bonding equipment
- Application of statistical methods for efficient big data processes and health monitoring
- Deployment of scalable monitoring and visualization tools in the IT infrastructure

3. Data Basis and Signal Characterization

- High-frequency process signals acquired during ultrasonic wire bonding
- Evaluation of deformation, current, voltage, and frequency traces
- Analysis performed at device and wire-position level
- Signals serve as the foundation for feature engineering and process health evaluation

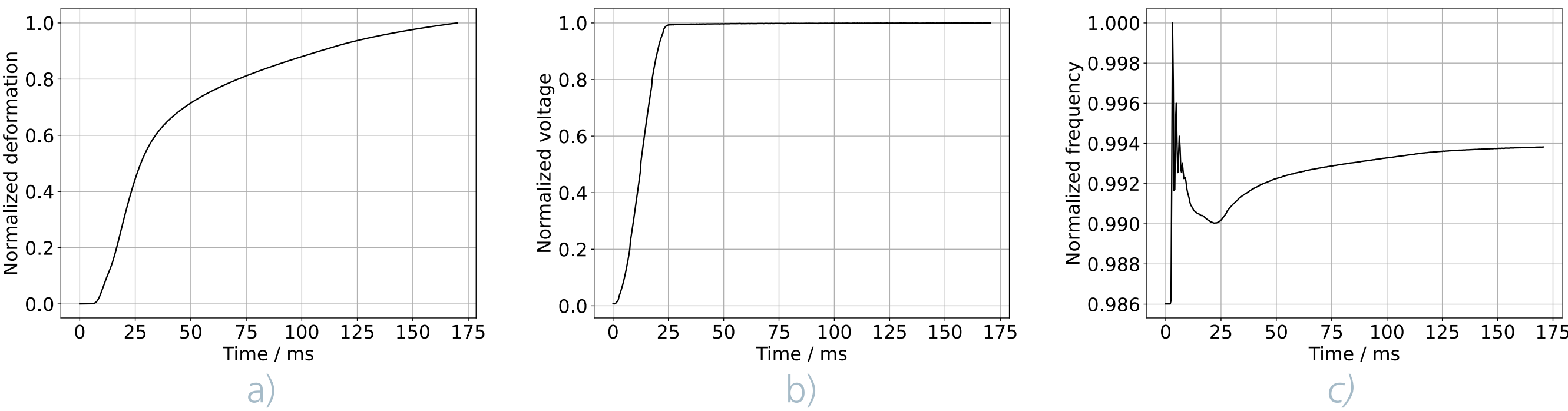


Fig. 1. Exemplary and normalized bond traces: a) deformation, b) voltage, c) frequency

4. Health Checker Framework

- Development of a modular, extensible “Health-Checker” framework
- Knowledge-based feature extraction
- Univariate statistical process control (SPC) using hierarchy-aware control charts
- Change-point detection for identifying distributional shifts and process drifts
- Multivariate health assessment based on Hotelling’s T^2 statistics
- Annotation workflow enabling curated datasets for future fault classification

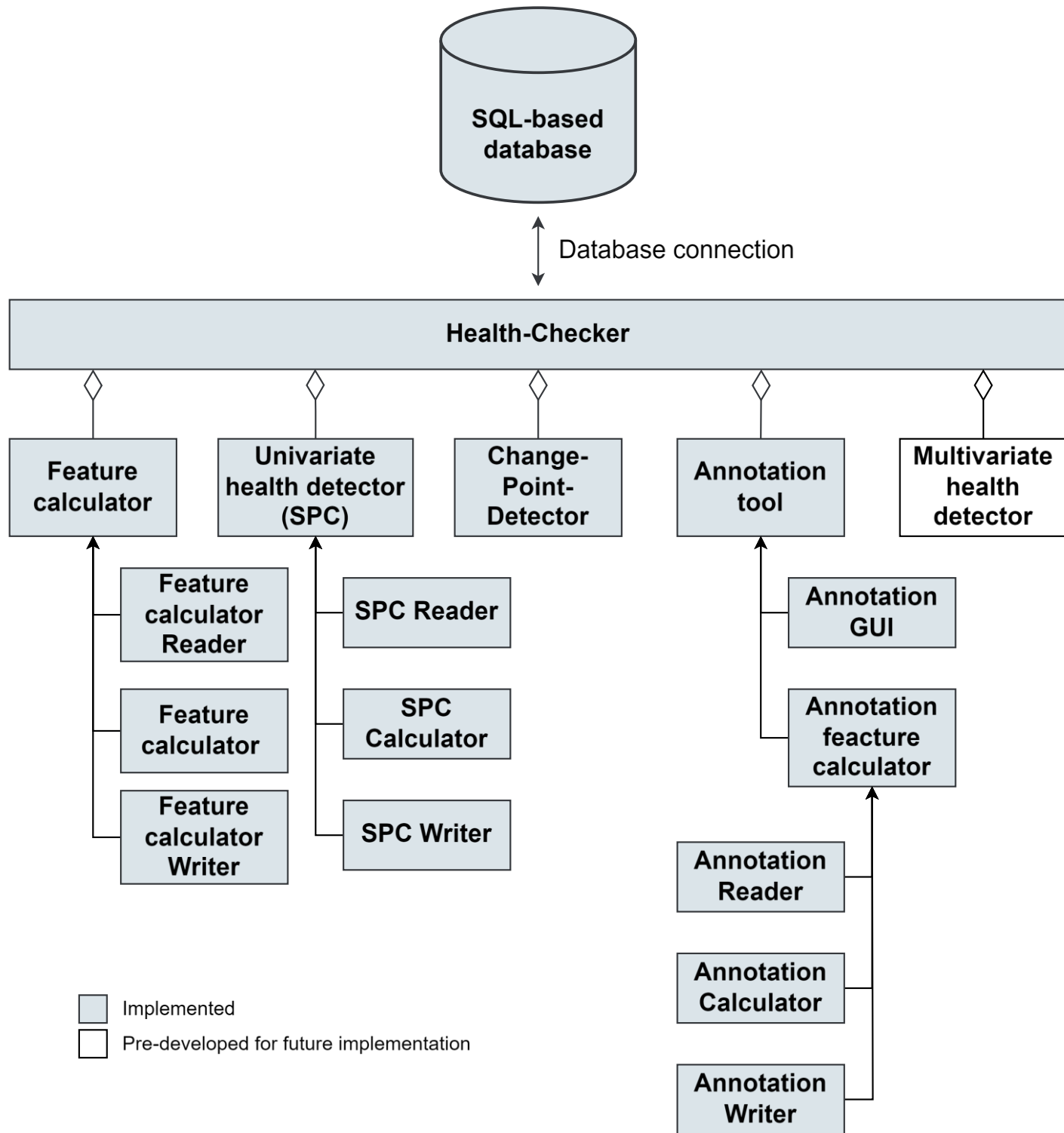


Fig. 2. Overview of the components of the Health-Checker framework

5. Data Pipeline and System Integration

- Tool-independent Extract–Transform–Load (ETL) workflow
- Standardized batch data extraction across bonding equipment
- Domain-driven data cleaning and feature computation
- Structured storage in databases for scalable analytics
- Seamless integration into existing manufacturing IT and MES environments

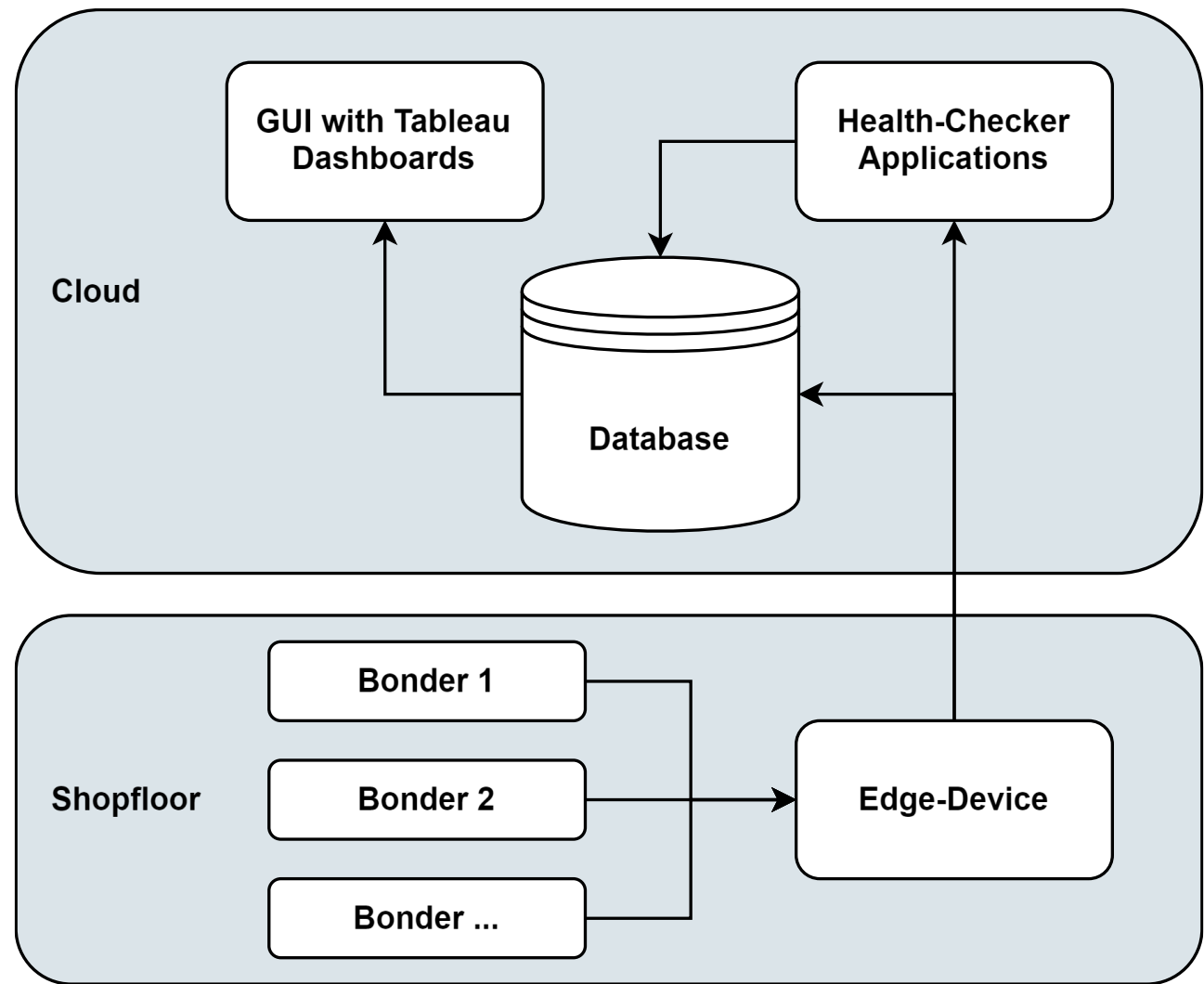


Fig. 3. Software architecture

6. Visual Analytics and Online Monitoring

- Interactive dashboards providing immediate access to process features and SPC charts
- Visualization of trends, drifts, and limit violations
- Support for rapid root-cause analysis and cross-functional collaboration
- Online availability for production, quality, and IT stakeholders.



Fig. 4. Visualization of corresponding Tableau dashboards: Domain-driven features (top), b) SPC features (bottom)

7. Results and Industrial Insights

- Successful deployment of integrated data analytics in an industrial production environment
- Harmonized cross-machine data analytics
- Early detection of process drifts related to tool wear and environmental effects
- Reduced reaction time through data-driven decision support
- Improved process understanding without reliance on destructive testing

8. Challenges and Lessons Learned

- Balancing false-alarm rates against missed defects
- Maintaining robust control limits after maintenance and product changes
- Ensuring traceability and interpretability of analytics results
- Importance of close collaboration between domain experts and data scientists

1 M. Hunstig, S. Holtkämper, L. Helmich, and M. Brökelmann, "Smart Ultrasonic Welding – A Versatile Interconnection Technology for Power Electronics Packaging," Additional Conferences (Device Packaging, HiTEC, HiTEN, and CICMT), vol. 2021, HiTEC, pp. 112–117, 2021, doi: 10.4071/2380-4491.2021.HiTEC.000112.
2 M. Hunstig, W. Schaermann, M. Broekelmann, S. Holtkaemper, D. Siepe, and H. J. Hesse, "Smart Ultrasonic Welding in Power Electronics Packaging," in CIPS 2020; 11th International Conference on Integrated Power Electronics Systems, 2020, pp. 1–6.