Requirements Document: BLE ECG/EEG Monitoring System

Document Information

- **Project Name**: Bluetooth Low Energy ECG/EEG Data Acquisition and Display System
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1. Project Overview

1.1 Purpose

This document outlines the requirements for developing a desktop application that receives ECG and EEG biometric data via Bluetooth Low Energy (BLE) communication and displays the data in real-time with graphical visualization, timestamps, and interval measurements.

1.2 Scope

The system consists of:

- BLE-enabled biometric sensors (ECG/EEG)
- Desktop frontend application for data visualization
- Real-time data processing and display capabilities
- Data logging and export functionality

1.3 System Context

The application will interface with medical-grade or consumer-grade biometric sensors that transmit ECG and EEG data over BLE protocol to provide healthcare monitoring, research data collection, or wellness tracking capabilities.

2. Functional Requirements

2.1 Bluetooth Low Energy Communication

REQ-BLE-001: The system SHALL establish and maintain BLE connections with compatible ECG/EEG devices

- Support BLE 4.0+ protocol stack
- Automatic device discovery and pairing
- Connection state management (connected, disconnected, reconnecting)
- Support for multiple simultaneous device connections

REQ-BLE-002: The system SHALL handle BLE data packet reception

- Parse incoming data packets according to device-specific protocols
- Validate data integrity and handle transmission errors
- Buffer incoming data to prevent data loss during processing

2.2 Data Acquisition

REQ-DATA-001: The system SHALL acquire ECG data parameters

- Heart rate measurements (BPM)
- R-R intervals
- ECG waveform data (mV amplitude over time)
- Lead-specific data if multi-lead ECG

REQ-DATA-002: The system SHALL acquire EEG data parameters

- Fp1 electrode measurements (frontal pole left)
- Additional electrode positions as configured (Fp2, F3, F4, etc.)
- Raw EEG signal data (µV amplitude over time)
- Frequency domain analysis (alpha, beta, theta, delta bands)

REQ-DATA-003: The system SHALL timestamp all incoming data

- High-resolution timestamps (millisecond precision minimum)
- Synchronization with system clock
- Timezone handling and UTC conversion capabilities

2.3 Data Processing

REQ-PROC-001: The system SHALL perform real-time signal processing

- Digital filtering (bandpass, notch filters for noise reduction)
- Baseline correction and drift compensation
- Artifact detection and marking
- Configurable sampling rate handling (typically 250-1000 Hz for ECG, 250-500 Hz for EEG)

REQ-PROC-002: The system SHALL calculate derived metrics

- ECG: Heart rate variability (HRV), QRS detection, interval measurements
- EEG: Power spectral density, frequency band analysis, signal quality indicators

2.4 User Interface Requirements

REQ-UI-001: The system SHALL provide a main dashboard interface

- Real-time data display panels
- Device connection status indicators

- Data quality indicators
- System configuration controls

REQ-UI-002: The system SHALL display real-time graphs

- Multi-channel waveform display (ECG leads, EEG channels)
- Configurable time windows (5s, 10s, 30s, 1min, 5min)
- Amplitude scaling controls
- Grid overlay and measurement cursors
- Color-coded channels with labels

REQ-UI-003: The system SHALL provide measurement displays

- Numerical readouts for key metrics (HR, intervals, amplitudes)
- Statistical summaries (min, max, mean, standard deviation)
- Trend graphs for long-term monitoring
- Alert indicators for abnormal values

2.5 Data Management

REQ-DATA-004: The system SHALL provide data storage capabilities

- Local file storage in standard formats (CSV, EDF, JSON)
- Session-based data organization
- Configurable storage duration and file rotation
- Data compression options for long-term storage

REQ-DATA-005: The system SHALL support data export

- Export selected time ranges
- Multiple file format support
- Metadata inclusion (timestamps, device info, settings)
- Batch export capabilities

3. Non-Functional Requirements

3.1 Performance Requirements

REQ-PERF-001: Real-time processing latency SHALL be < 100ms from data reception to display update

REQ-PERF-002: The system SHALL support continuous operation for minimum 8 hours without performance degradation

REQ-PERF-003: Memory usage SHALL not exceed 2GB during normal operation

REQ-PERF-004: The system SHALL handle data rates up to 2000 samples/second per channel

3.2 Reliability Requirements

REQ-REL-001: The system SHALL maintain 99.5% uptime during active monitoring sessions

REQ-REL-002: Data loss SHALL not exceed 0.1% of transmitted packets under normal operating conditions

REQ-REL-003: The system SHALL gracefully handle device disconnections and implement automatic reconnection

3.3 Usability Requirements

REQ-USE-001: The interface SHALL be operable by users with basic computer skills and minimal training

REQ-USE-002: Critical functions SHALL be accessible within 3 clicks from the main interface

REQ-USE-003: The system SHALL provide contextual help and error messages

3.4 Security Requirements

REQ-SEC-001: All stored biometric data SHALL be encrypted using AES-256 encryption

REQ-SEC-002: BLE communication SHALL use device pairing and authentication

REQ-SEC-003: The system SHALL provide user access controls and audit logging

4. Technical Requirements

4.1 Platform Requirements

REQ-TECH-001: Desktop application compatible with:

- Windows 10/11 (x64)
- macOS 10.15+ (Intel/Apple Silicon)
- Linux Ubuntu 20.04+ (x64)

4.2 Hardware Requirements

REQ-TECH-002: Minimum system specifications:

- 8GB RAM
- 2GB available storage
- Bluetooth 4.0+ adapter
- Dual-core processor 2.0GHz+
- Graphics support for hardware acceleration

4.3 Software Architecture

REQ-ARCH-001: The application SHALL use a modular architecture with separated concerns:

- BLE Communication Module
- Data Processing Engine
- User Interface Layer
- Data Storage Manager
- Configuration Manager

REQ-ARCH-002: The system SHALL support plugin architecture for:

- Additional device support
- Custom signal processing algorithms
- Export format extensions

4.4 Development Framework

REQ-DEV-001: Recommended technology stack:

- **Frontend**: Electron.js with React/Vue.js or native frameworks (Qt, .NET, Flutter Desktop)
- **BLE Communication**: Noble.js (Node.js) or platform-specific BLE APIs
- **Signal Processing**: Web Audio API, DSP libraries, or native signal processing libraries
- **Visualization**: Chart.js, D3.js, or specialized medical charting libraries
- **Database**: SQLite for local storage

5. Data Specifications

5.1 ECG Data Format

```
{
  "timestamp": "2025-05-27T10:30:45.123Z",
  "device_id": "ECG_DEVICE_001",
  "lead_data": {
    "lead_I": 0.45,        // mV
    "lead_II": 0.78,       // mV
    "lead_III": 0.33       // mV
  },
  "heart_rate": 72,        // BPM
  "rr_interval": 833,      // milliseconds
  "signal_quality": 95     // percentage
}
```

5.2 EEG Data Format

```
{
  "timestamp": "2025-05-27T10:30:45.123Z",
  "device_id": "EEG_DEVICE_001",
  "electrode_data": {
```

```
    "Fp1": 12.5,           // µV
    "Fp2": 15.2,           // µV
    "F3": 8.7,             // µV
    "F4": 11.3             // µV
  },
  "frequency_bands": {
    "delta": 2.1,          // µV²
    "theta": 1.8,          // µV²
    "alpha": 3.2,          // µV²
    "beta": 1.5            // µV²
  },
  "signal_quality": 88  // percentage
}
```

6. User Interface Mockup Requirements

6.1 Main Window Layout

- Header: Device status, connection indicators, system time
- Left Panel: Device list, connection controls, settings
- Center Panel: Real-time waveform graphs (primary display area)
- Right Panel: Numerical measurements, alerts, statistics
- Bottom Panel: Recording controls, export options, status bar

6.2 Graph Display Specifications

- Minimum 4 simultaneous waveform channels
- Configurable amplitude scales (auto-scale, fixed scale)
- Time axis with configurable sweep speeds (25mm/s, 50mm/s standards)
- Measurement cursors with delta time/amplitude display
- Zoom and pan capabilities
- Export graph as image functionality

7. Integration Requirements

7.1 Device Compatibility

REQ-DEVICE-001: The system SHALL support standard BLE biometric device profiles:

- Heart Rate Service (HRS)
- Health Thermometer Service
- Custom manufacturer-specific services

REQ-DEVICE-002: The system SHALL provide device configuration interface for:

- Sampling rate settings
- Filter configurations
- Calibration parameters
- Channel selection

8. Testing Requirements

8.1 Unit Testing

- BLE communication module testing with mock devices
- Signal processing algorithm validation
- Data storage and retrieval testing
- UI component testing

8.2 Integration Testing

- End-to-end data flow testing
- Multi-device connection testing
- Long-duration stability testing
- Cross-platform compatibility testing

8.3 User Acceptance Testing

- Healthcare professional workflow validation
- Usability testing with target user groups
- Performance testing under realistic usage scenarios

9. Constraints and Assumptions

9.1 Constraints

- Regulatory compliance may be required for medical applications
- BLE range limitations (typically 10-30 meters)
- Platform-specific BLE API differences
- Real-time processing limitations based on hardware capabilities

9.2 Assumptions

- Users have basic familiarity with biometric monitoring concepts
- BLE devices conform to standard service specifications or provide adequate documentation
- Network connectivity available for software updates and data synchronization (optional)
- Users will provide appropriate consent for biometric data collection and storage

10. Acceptance Criteria

10.1 System Acceptance

The system is considered acceptable when:

- All functional requirements are implemented and tested
- Performance benchmarks are met

- User interface passes usability testing
- Data accuracy is validated against reference devices
- Cross-platform deployment is successful

10.2 Deliverables

- Compiled desktop application installers for target platforms
- User documentation and installation guides
- Technical documentation and API references
- Test reports and validation data
- Source code with appropriate licensing

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