

An Extensible Cloud Platform for Integrating Heterogeneous IoT Devices in Physiological and Behavioral Research

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Clinical diagnostics increasingly rely on data from multiple physiological sensors, but integrating these heterogeneous data streams for a single patient remains a significant technical challenge. In this paper, we present the architecture and implementation of a low-cost, modular, cloud-based software portal designed to centralize the recording of data from various sensor-based medical devices for a unified patient record. The platform leverages the MQTT protocol for reliable data transmission, a PHP/MySQL backend for data management, and a Python-based service for data logging. A key feature is the Role-Based Access Control (RBAC) system, ensuring data privacy for different user types such as researchers and patients. To demonstrate its versatility, the platform was successfully validated by integrating three distinct proof-of-concept (PoC) devices developed in our lab: a cardiovascular stress monitor (GSR/HR), an oculomotor behavior analysis system (eye-tracker) and a psychomotor assessment tool (finger tapping). Our results show that the proposed infrastructure provides a flexible and accessible solution for creating comprehensive, multi-modal data sets for diagnostic purposes.

Keywords—IoT, Physiological Monitoring, e-Health, Cloud Platform, Eye-Tracking, Stress Analysis, Data Acquisition, MQTT, RBAC Physiological Monitoring

I. INTRODUCTION

The collection of physiological and behavioral data is fundamental to advancing our understanding in fields ranging from major subfield of psychology to human-computer interaction. However, researchers are often constrained by commercial data acquisition systems that are expensive, proprietary, and inflexible. These closed-box systems typically do not allow for the integration of custom or heterogeneous sensors, forcing researchers to work within silos and limiting the scope of multi-modal studies. Furthermore, the technical overhead of setting up and managing the data infrastructure for such studies can be substantial, diverting valuable time and resources away from the primary research questions. [1], [2]

Recent advancements in the Internet of Things (IoT) and low-cost sensor technologies present an opportunity to

overcome these barriers. While several platforms have been proposed for IoT health monitoring, there remains a need for a truly open and extensible architecture that can serve as a common backbone for diverse research projects within a single institution.

Our primary contribution is the design, implementation, and validation of such a platform. We present an IoT-based infrastructure that is both low-cost and highly modular, capable of acquiring, storing, and visualizing data from a heterogeneous set of data acquisition nodes. This paper details the platform's multi-layered architecture and demonstrates its practical utility through three distinct case studies developed in our laboratory. Section II describes the system architecture. Section III presents the three proof-of-concept implementations. Section IV discusses the results and limitations, and Section V provides the conclusion and outlines future work.

II. SYSTEM ARCHITECTURE

A. Overview

The platform follows a layered design to preserve modularity and separation of concerns: acquisition nodes → MQTT broker → Python ingestion service → MySQL database ↔ PHP web portal.

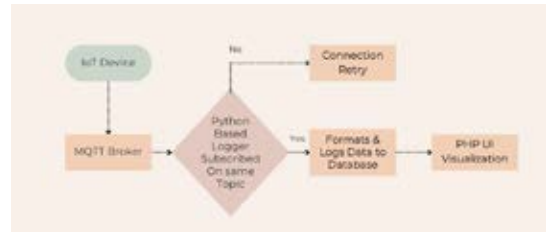


Fig. 1 summarizes the end-to-end flow from device to visualization.

B. Data Acquisition Layer



Acquisition nodes include (1) microcontroller-based wearables (e.g., ESP32) producing continuous or event data, and (2) computer-based systems (e.g., eye-tracker software) streaming higher-rate, multidimensional signals. Nodes are hardware-agnostic; the sole requirement is publishing well-formed messages to MQTT topics.

Fig. 2. Suggested topic scheme:

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["mac_address":"3C:8A:1F:A3:CF:C4","start_timestamp":264795,"sample_count":100,"frequency":100,"average_bpm":148,"gcr_value":498,"r_value":179,21167,21114,21179,21080,21089,21099,21082,21083,21113,21110,21096,21047,21131,21049,21067,21103,21120,21123,21069,21094,21150,21175,21144,21127,21122,21119,21138,21120,21108,21062,21160,21103,21086,21106,21135,21140,21136,21103,21136,21125,21147,21076,21180,21136,21131,21131,21096,21140,21137,21126,21104,21119,21125,21113,21117,21111,21127,21099,21082,21131,21110,21194,21080,21107,21106,21100,21125,21137,21076,21129,21143,21116,21182,21116,21120,21163,21158,21091,21157,21150,21183,21107,21177,21159,21123,21113,21130,21079,21061,21116,21082,21116,21086,21065,21097,21095,21114,21168]

["mac_address":"3C:8A:1F:A3:CF:C4","start_timestamp":263795,"sample_count":100,"frequency":100,"average_bpm":160,"gcr_value":471,"r_value":109,21050,21050,21123,21053,21112,21125,21110,21131,21084,21146,21091,21136,21146,21158,21094,21145,21086,21126,21074,21114,21158,21083,21150,21081,21135,21116,21107,21128,21136,21117,21097,21096,21126,21096,21114,21129,21132,21135,21122,21118,21188,21139,21147,21188,21133,21133,21076,21126,21122,21144,21152,21113,21090,21084,21147,21161,21112,21131,21136,21182,21093,21139,21109,21140,21141,21152,21142,21185,21168,21093,21093,21188,21096,21142,21120,21065,21116,21088,21084,21083,21099,21175,21099,21117,21038,21043,21085,21127,21106,21066,21192,21125,21183,21107,21174,21184,21168,21144,21213,21161]
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C. Communication Layer (MQTT)

We employ MQTT due to its lightweight publish-subscribe semantics, tolerance to intermittent connectivity, and widespread device support. Devices publish to project-scoped topics; the ingestion service subscribes with appropriate QoS and authentication. This decoupling allows devices and backend to evolve independently. [14]

D. Cloud Backend Layer

Ingestion Service (Python): A persistent daemon subscribes to project topics, parses JSON payloads, validates required fields, and writes to the database. It also logs operational metrics (throughput, drop rate, end-to-end latency) for observability.

Database (MySQL): The schema uses four core tables—users, devices, recordings, measurements—with foreign-key constraints. We extend devices with device_type; recordings store protocol metadata (start/end timestamps, notes); measurements persist high-frequency samples as typed rows (stream, ts, data_json). This flexible design admits time-series, event-based, and multidimensional data.

Web Portal (PHP): The portal implements (i) device registration and ownership; (ii) RBAC enforcing per-role visibility; (iii) an experiment dashboard to start/stop recordings and attach contextual annotations; (iv) live charts and CSV download for offline analysis. Role set: admin (system-wide), researcher (authorized multi-participant access), clinician (assigned patient cohort), participant (self-data only). Passwords are hashed (e.g., Argon2) and sessions use secure cookies.

Fig. 3. Device management page – register device by name and MAC; list with status.

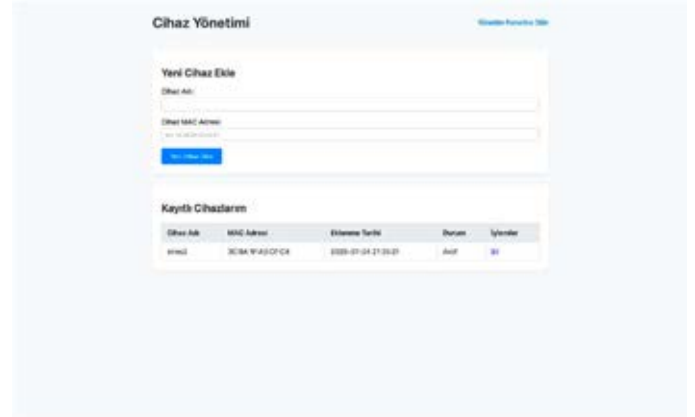
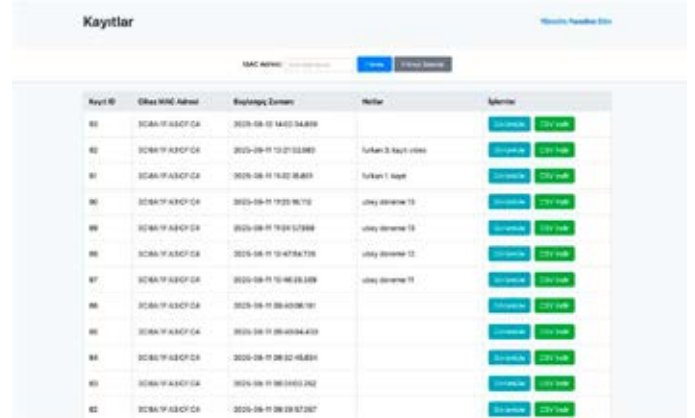
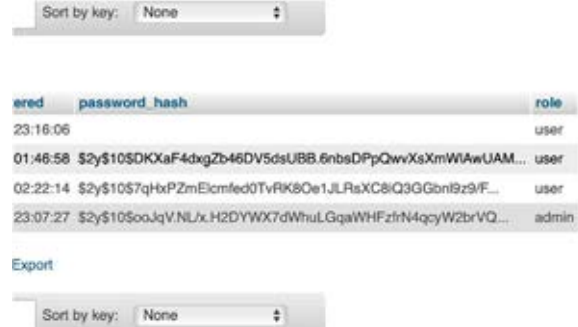


Fig. 4. Records list – filter by MAC; view or download CSV.



E. Security and Privacy

Traffic is protected via TLS; user access follows least privilege via RBAC. Participants are represented by pseudonymous identifiers; audit logs capture access. Future enhancements include mutual-TLS for device authentication and automated device claiming (Section V).



III. STUDIES: PROOF-OF-CONCEPT IMPLEMENTATIONS

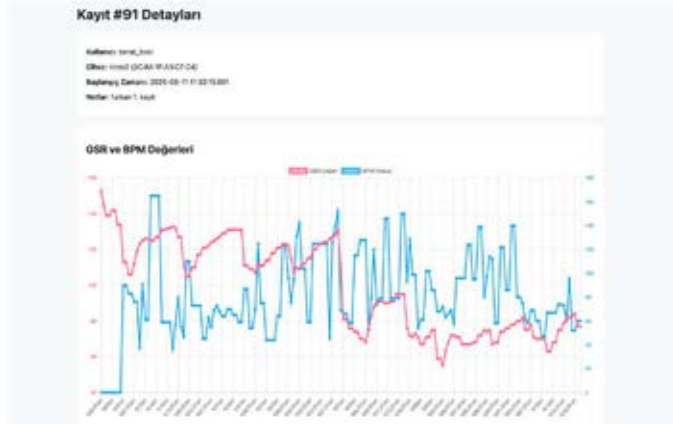
A. Cardiovascular Stress Monitoring (GSR/HR)

GSR relies on the fact that human skin contains numerous sweat glands, particularly in areas such as the palms and fingertips, which are innervated by the sympathetic branch of the autonomic nervous system. When a person experiences emotional arousal or stress, sympathetic activation stimulates

these sweat glands to secrete moisture, even at levels too subtle to be visibly detected. [22]

Objective: infer stress responses using galvanic skin response and photoplethysmography-derived heart rate/variability. Data: continuous time-series (e.g., GSR, IR, BPM). Integration: the proto-device publishes per-sample payloads to MQTT; the ingestion service writes samples to measurements; the dashboard provides live plots and session-level notes (e.g., “Stroop start”, “Rest”). Outcome: researchers visualize artifacts in real time and export sessions for HRV analysis. [4], [9], [19], [20]

Fig. 5. Record detail view – synchronized GSR and BPM time series (sample session).



B. Eye-Tracking Proof-of-Concept (Dynamic Calibration Approach)

Eye movements reveal aspects of problem solving, reasoning, mental imagery, and search strategies, behavioral studies often use objective methods to examine these relationships during visual tasks by using eye-tracking [23].

This PoC implements a webcam-based, software-only eye-tracking approach with dynamic calibration. During a ~40-second calibration, thousands of (feature, target) pairs are collected while the user tracks a smoothly moving target; each frame is labeled with the target's on-screen (x, y) coordinates and a compact eye feature vector. A LightGBM model is trained per user to map features to gaze coordinates, and a Kalman filter stabilizes predictions. Compared to classical 9/16-point static calibration, the dense, person-specific map reduces error and is more tolerant to head drift. The pipeline runs with Python/OpenCV/MediaPipe and streams outputs to the cloud backend for storage and visualization.

C. Psychomotor Skills Analysis (Finger-tapping)

The finger-tapping test (FTT) provides a simple yet sensitive measure of motor speed and coordination, which are closely linked to both cognitive performance and overall neurological health. Because it can detect subtle motor slowing

or asymmetry, the FTT offers an objective, quantifiable metric for tracking changes in motor function over time or in response to interventions. [21]

We collect per-keystroke timestamps to compute simple speed/regularity summaries; detailed clinical analysis is outside the scope of this platform paper.

DISCUSSION

Storing GSR, eye-tracking, and finger-tapping data in a unified cloud-based platform enables seamless integration and large-scale analysis of multimodal physiological and behavioral measures. By combining indicators of GSR, eye tracking, and finger tapping, researchers can develop a more comprehensive understanding of human behavior across sensory, cognitive, and motor domains.

Benefits: (i) extensibility—new devices integrate by topic and payload conventions; (ii) centralization—single storage and portal reduce friction; (iii) collaboration—role-aware remote access for multi-site studies; (iv) low cost—commodity IoT hardware and open-source stack. Limitations: current device onboarding is manual (MAC-based), and high-rate streams rely on careful broker and DB tuning. Threats to validity include small-scale lab deployment and limited diversity of devices so far.

Evaluation plan: measure end-to-end latency (publish to plot), throughput (messages/s), data loss, and setup effort per PoC; report per-role access correctness via test scenarios. (Insert results once experiments are consolidated.)

IV. CONCLUSION AND FUTURE WORK

We introduced a role-based cloud platform unifying heterogeneous IoT physiological/behavioral data and validated it with three distinct PoCs (Stress Measurement, Eye Tracking, Fingertapping). The unified schema and messaging allowed plug-and-play integration without backend changes. Next steps include (i) device claiming for non-technical onboarding (e.g., QR-based claim, pending→verified workflow), and (ii) embedded machine-learning services for on-portal inference (e.g., real-time stress classification), alongside broader multi-site deployment.



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