SMART INFANT HEALTH MONITORING SYSTEM WITH IOT-BASED FAILOVER MECHANISMS FOR RURAL AREAS

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Keywords:

Internet of Things, Remote Infant Health Monitoring System, Human-centred AI, Contactless Sensor Technologies, Failover Mechanism

Introduction:

In March 2017, rural India experienced a 20.3% shortage of staff nurses at primary health centers (PHCs) and community health centers (CHCs) (Saikia, 2018, ResearchGate). In addition to the lack of 454 Primary Health Centers (PHCs) that have not yet been built, Bengaluru Urban, Belagavi, Mysuru, Tumakuru, Hassan, and Mandya account for 39.1% of Karnataka's nursing staff shortage, which exacerbates healthcare access in rural areas, according to an article in the Indian Express (2023).

The project aims to remotely monitor infants' health in resource-limited areas, reducing infant mortality and Sudden Infant Death Syndrome (SIDS). By leveraging IoT for continuous monitoring and AI for predicting potential health issues, it ensures early detection of vital abnormalities such as temperature, heart rate, oxygen levels, and more. The solution is designed to function both offline and with low connectivity, making it accessible in rural or under-served regions. It also addresses issues like delayed healthcare intervention, environmental safety, and affordability by creating a cost-efficient, rental-based device accessible to a broader demographic. The project seeks to provide parents with peace of mind, while also improving health equity and safety through enhanced monitoring and early interventions.

Objectives:

1. To develop a low-cost, AI-powered IoT system for offline, real-time, 24/7 support for infant vital monitoring and early health alerts in undeserved regions.
2. Using contact-less sensors and Infrared Cameras to avoid irritation to Infants provide non-invasive contact-less support.
3. Low-cost, user-friendly, portable, and plug-and-play hardware.
4. Real-time AI Agent powered by Language Models using BLE used for Fail-over mechanism due to the absence of Internet Connectivity.
5. SOTA AI Model to monitor Infant Activity Monitoring and Heart Rate Variability with SpO2 using Signal Processing.
6. User friendly Web Application using MERN stack for Healthcare Professionals and Mobile Application using Flutter for Parents/ Caregivers for real time alerts and Insights.
7. Integrate IoT with Cloud infrastructure (AWS) for Scalability.

Methodology:

Our proposed solution aims to create a low-cost, AI-enabled Remote Infant Monitoring System using the Internet of Things (IoT) using non-contact sensors with a Failover Mechanism that works even in the absence of the Internet for connectivity in rural/remote areas.

Our solution uses non-contact sensors instead of Wearables as they cause discomfort to the infant and moisture, etc. from the baby might affect the effectiveness of the sensors. We have continuous monitoring which can be remotely monitored by Health professionals and Parents in real-time. There is a separate UI for Parents and Health Professionals which will be built using Flutter. Real-time AI predictions and Detections to predict and mitigate health issues and take timely actions. Alongside Object detection to detect the Safe state of the Infant in terms of Position as well as safety from pests. An edge deployed (within the Raspberry Pi Controller) as well as cloud-deployed ML Models for online and offline predictions and monitoring. Infant Health AI

Agent powered by open Source LLMs for offline (Lack of Internet) situations to assist the mother during emergencies, etc. It notifies the nearest Primary Health Centre (and Ambulance Service if needed) and it gives parent's necessary steps and instructions to be followed during emergency services.

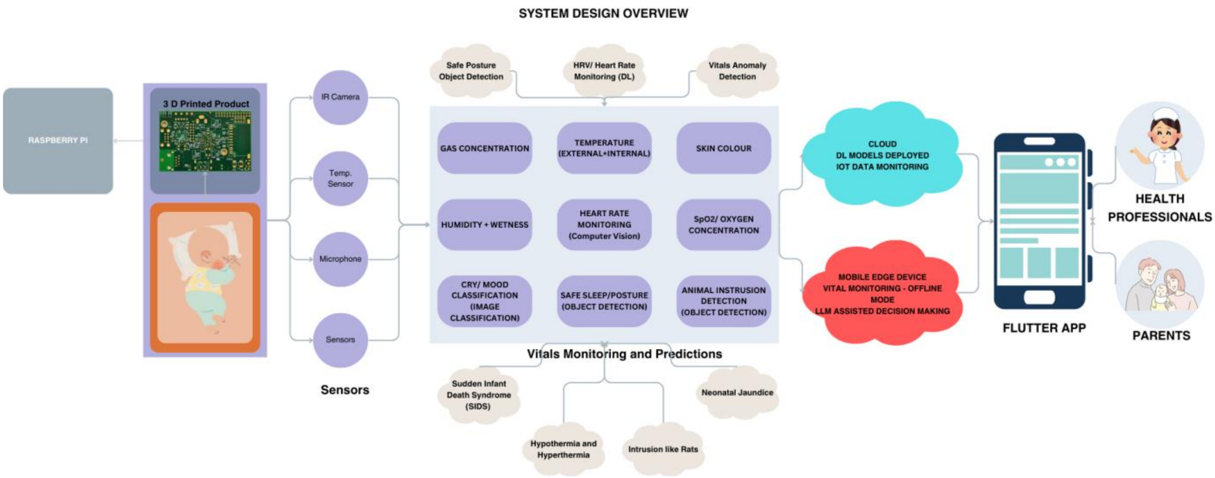

Figure 1: System Design Overview

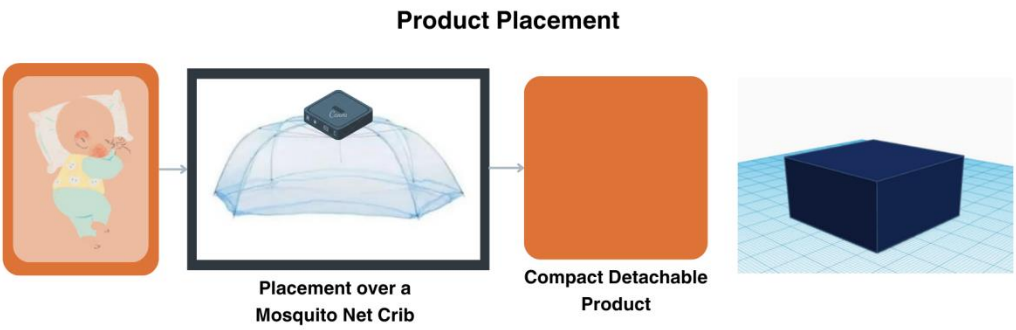

Figure 2: Product Placement

Figure 2 describes the product placement of the hardware. The plug and play hardware can be attached to a low cost mosquito net and also can be integrated with existing NICU systems and Cribs.

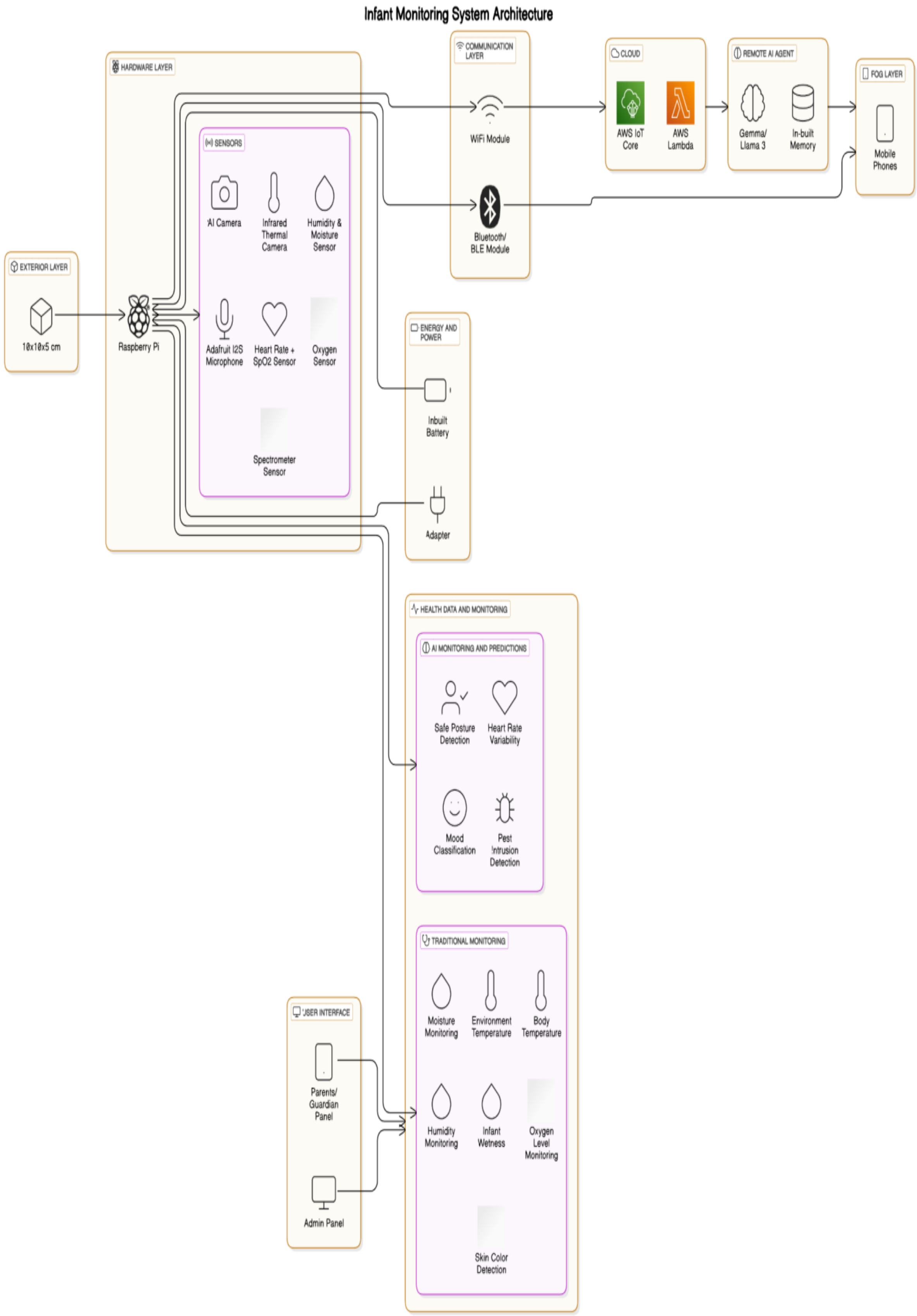

Figure 3: High Level System Design

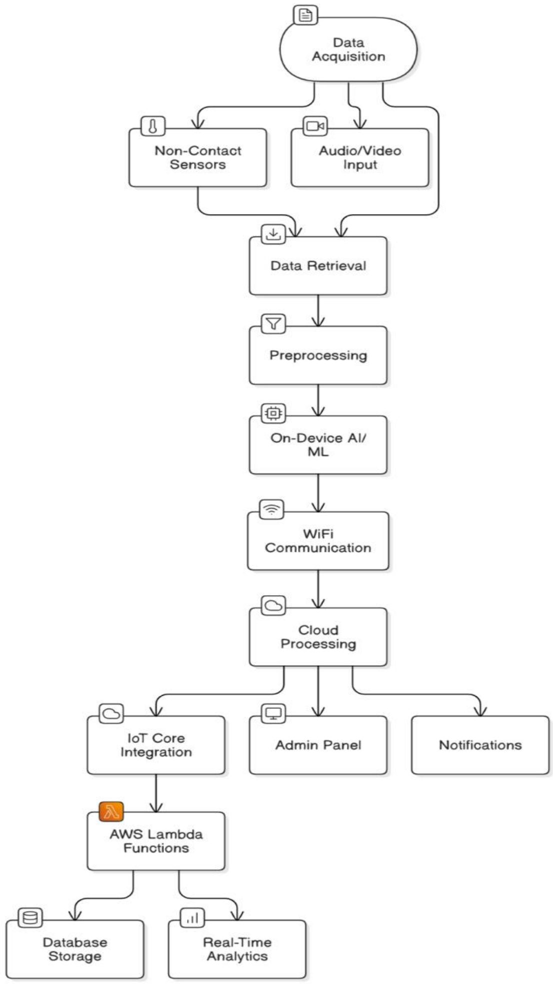

Figure 4: High Level Data Flow Diagram

- Enclosure Design: 10x10x5 cm waterproof PVC casing with clip-on mount; ensures IP65 protection for embedded electronics and passive ventilation for sensor accuracy.
- Edge Compute Node: Raspberry Pi 5 (ARM Cortex-A76, 8GB RAM) acts as fog node for local sensor integration, real-time inference, and protocol bridging.
- Optical Sensing: Raspberry Pi NoIR Camera Module 3 (HDR, IR sensitivity) captures multi-spectral imagery; utilized for biometric signal extraction and visual inference.
- Core Sensors:
    - MLX90614: IR-based body temperature (non-contact, -70°C to +380°C).
    - DHT11: Ambient temperature (±2°C) and relative humidity (±5%).
    - MQ135: Air Quality Index (NH3, NoX, alcohol, benzene, smoke).
- Communication Stack:

    - MQTT : Sensor-to-cloud, QoS 1 protocol for lightweight telemetry.
    - HTTPS (TLS 1.3): Cloud-to-web/app data transfer via RESTful services. BLE 5.0: For local/offline mesh communication and edge-level data synchronization.
- Conventional Health Metrics: Tracks core infant vitals—body temperature, humidity, bed wetness detection, air pollutants, and skin chromaticity (bilirubin inference via image analysis).
- Safe Sleep Posture Detection: YOLOv8 model (fine-tuned on augmented datasets); deployed with ONNX runtime; triggered every 30s interval on Pi via OpenCV pipeline.
- Heart Rate & SpO2: Remote photoplethysmography (rPPG) via IR+RGB stream; CNN-based ROI localization + signal processing using OpenCV (FFT/ICA) for HRV and oxygen estimation.
- Mood Estimation: RT-DETR (Real-Time Detection Transformer) trained with facial expression datasets; optimized with quantization-aware training (QAT) for ARM deployment.
- Rodent Intrusion Detection: Object detection pipeline trained with COCO-style pest datasets (YOLOv8m); motion-triggered image capture.
- Cloud Pipeline:
    - MQTT Broker: AWS IoT Core. Data Processing: AWS Lambda + DynamoDB for event-driven microservice processing.
    - API Layer: Express.js RESTful endpoints with authentication middleware.

- Remote AI Agent: Inference runtime powered by Ollama on-device; LLaMA 3 and Gemma models fine-tuned for pediatric query-response and medical context summarization.MemGPT agent stores and compresses temporal summaries of health logs and sensor state deltas.Chain-of-Thought reasoning schema generates multi-step medical insights with confidence scoring, routed to the admin dashboard.
- Web Interface: MERN stack (MongoDB, Express, React, Node.js) with OAuth2 for clinician dashboards; integrates real-time MQTT stream visualizations using Chart.js.

- Mobile Client: Flutter-based mobile app; BLE+HTTP hybrid architecture; supports offline data caching via Hive DB and push alerts via Firebase Cloud Messaging.
- Database Architecture:
    - Health Data: MySQL (relational) and Firebase Realtime DB for mirrored NoSQL storage.
    - Auth/Profiles: Firebase Authentication with role-based access control.
    - Alert System: Real-time anomaly detection triggers alerts; uses pre-defined health thresholds + model outputs for alerts via SMS, email, or in-app notifications.
- Emergency Protocols: SOS button in app triggers webhook to ambulance services; integrates with third-party telehealth APIs for live consultations.
    - Validation Workflow:
      Clinical Feedback Loop: Continuous fine-tuning via doctor validation dashboards.
    - Sensor Calibration Checks: Scheduled signal quality index (SQI) assessment.
    - Model Drift Handling: CI/CD pipeline for model updates triggered by feedback + accuracy thresholds.

Result and Conclusion:

Till now, the following have been already implemented and tested.

- Infant Activity and Pest Intrusion Detection:

Model	Precision	Recall	mAP@50	mAP@95
YOLO V8	0.85	0.842	0.915	0.733
RT-DETR	0.841	0.836	0.9	0.73
YOLO V10	0.837	0.836	0.899	0.723

Table 1: Infant Activity and Pest Intrusion Detection Accuracy Metrics

Figure 5: Sample Inference of the Infant Activity and Pest Intrusion Detection Model

- Infant Safe Sleep Detection:

Model	Precision	Recall	mAP@50	mAP@95
YOLO V8	0.824	0.854	0.91	0.63
RT-DETR	0.8	0.83	0.89	0.54
YOLO V10	0.81	0.8	0.867	0.43

Table 2: Infant Safe Sleep Detection Accuracy Metrics

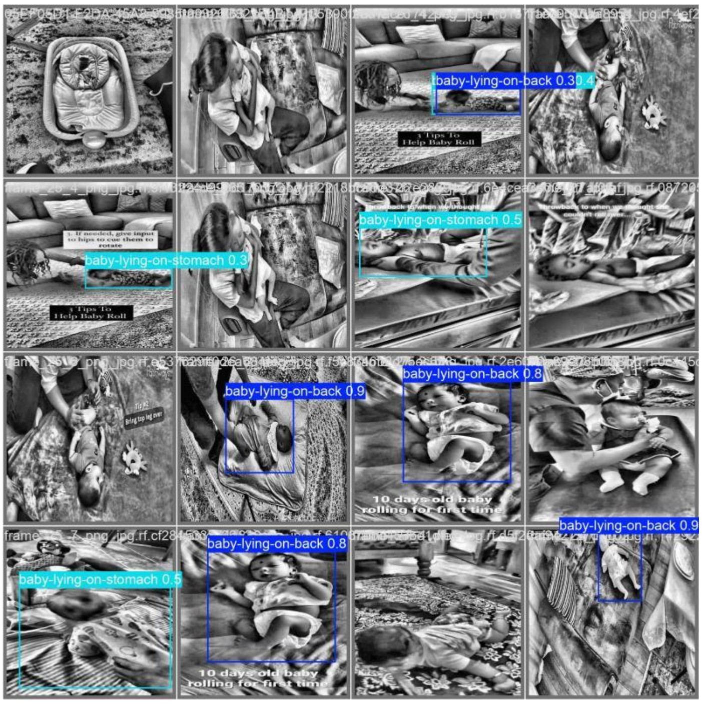

Figure 6: Sample Inference of the Infant Safe Sleep Detection Model

- Heart Rate Variability (HRV) and Sp02 via IR Camera using CNN/YOLO Localization and OpenCV Signal Processing to detect the RGB Channels and absorption of oxygen.
- Website using MERN Stack

  Used React.js and node.js for frontend and backend integration. Incorporated chart.js for graphs.

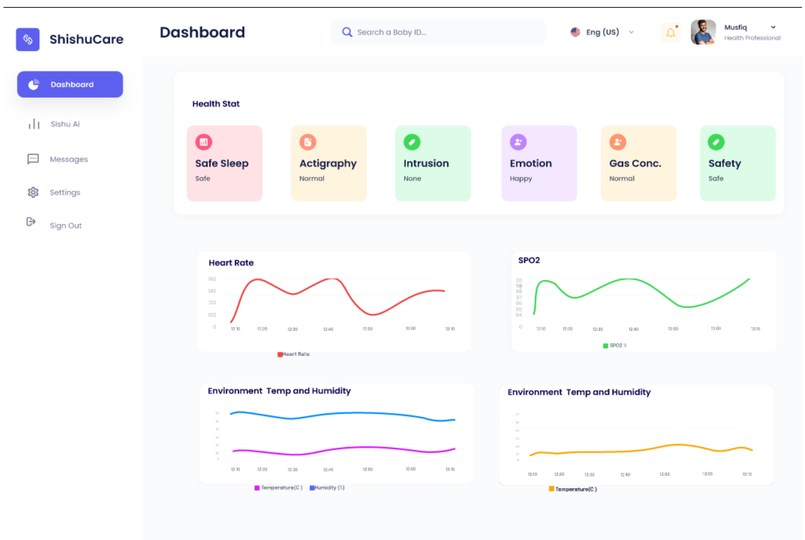

Figure 6: MERN Stack Website UI of our Admin/Healthcare Panel

- Mobile Application using Flutter

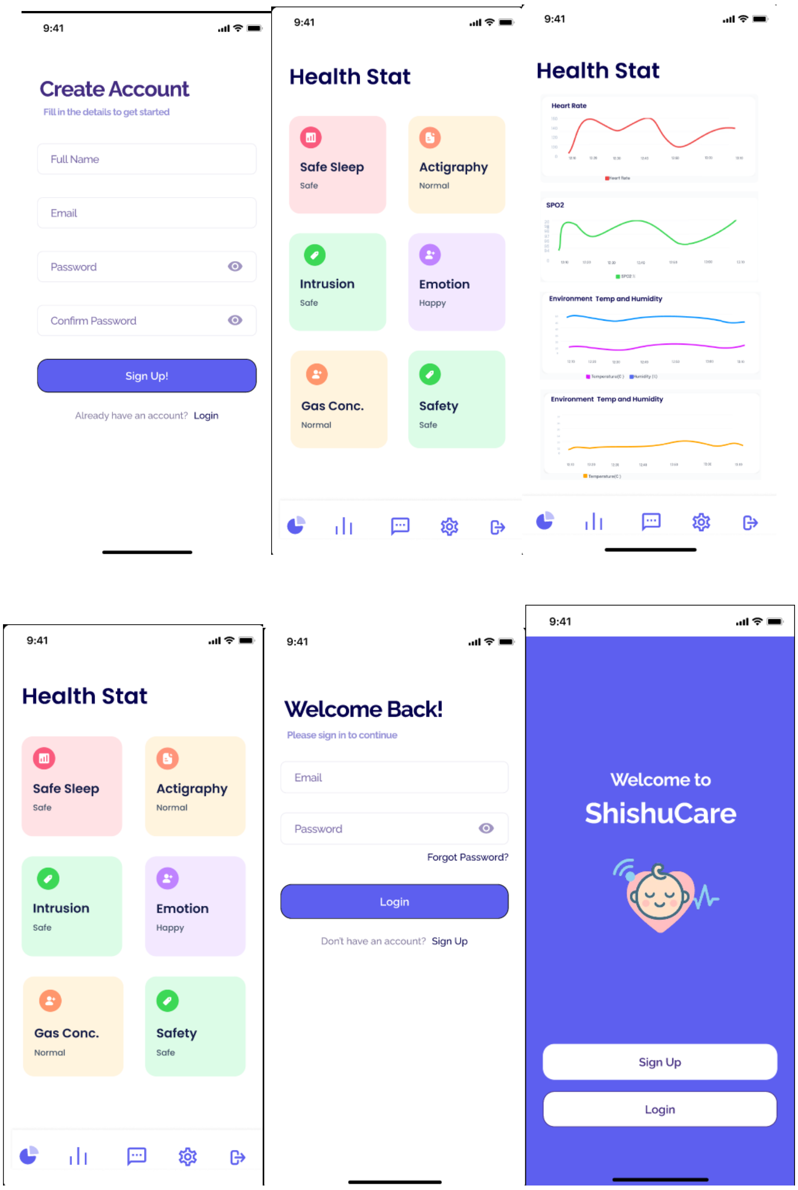

Figure 7: MERN Stack Website UI of our Admin/Healthcare Panel

- Circuit Design of Raspberry Pi and the sensors

Only the IoT integration with cloud and website is left with implementation of remote AI agents.

The Remote Infant Health Monitoring system with Failover Mechanism for Rural Areas, with offline support through reliable failover mechanisms, bridges the gap between healthcare professionals and parents in rural and underprivileged areas. By leveraging IoT and AI, it enables real-time monitoring, early health interventions, and accurate predictions, reducing infant mortality and improving healthcare access. The solution is cost-effective, scalable, and validated by doctors, enhancing trust and healthcare infrastructure while ensuring long-term benefits for infant health and safety.

Project Outcome & Industry Relevance

The project delivers a real-time infant health monitoring system using IoT and AI to track vital signs like heart rate, temperature, respiration, and body movement. It ensures continuous monitoring through offline data processing enabled by edge computing and local storage. Failover mechanisms such as Bluetooth,AI Agent and offline mobile apps maintain data communication even without internet connectivity. The system integrates blockchain technology to secure and validate health records, while AI/ML models provide early alerts for critical conditions like SIDS or infections. Designed to be cost-effective and scalable, the solution is particularly suited for rural and underserved areas. Effective implementation from rural homes or PHCs. Beyond healthcare technology, the solution aligns with public health governance frameworks and can be integrated into telemedicine services and local primary health centers (PHCs). It empowers rural healthcare delivery systems by supporting Self-Help Groups (SHGs), Accredited Social Health Activists (ASHAs), and Anganwadi workers with mobile-based dashboards and alerts, enhancing community-level decision-making. This project contributes to social good by bridging the rural healthcare gap,UN SDGs, supporting Health 4.0 goals, and promoting inclusive access to neonatal care through technology-driven public health models.

This project will also proceed onto getting a Design Patent filed.

Working Model vs. Simulation/Study

Working model with end to end deployment with hardware. To be tested in real world situations such as hospitals (already in touch with hospitals for testing the prototype).

Future Scope:

- Integration with national health portals like Ayushman Bharat and eSanjeevani for unified health records.
- Expansion to other use cases such as maternal care, postnatal care, and elderly health monitoring.

- Deployment of TinyML for ultra-low-power AI processing directly on wearable/edge devices.
- Advanced AI models for predicting chronic conditions, infections, or developmental delays.
- Offline-first mobile apps with voice-enabled, multilingual interfaces for rural users.
- Blockchain-enabled secure medical records with verifiable health history and access control.
- Collaboration with SHGs, ASHAs, and NGOs for grassroots deployment and awareness building.
  Human-centered design for intuitive interfaces catering to low-literacy populations.
  Wearable and ambient sensor research for more accurate and non-invasive monitoring.
- Ethical AI and health data governance frameworks to ensure responsible technology use. Impact evaluation studies to validate health and social benefits in real-world settings.
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