📘 PROJECT REPORT:

AI-Powered IoT-Based Real-Time Sleep Apnea Detection System

Real-Time Home Health Monitoring & Early Risk Screening Platform

---

1. ABSTRACT

Sleep apnea is a widespread but under-diagnosed sleep disorder that causes repeated breathing interruptions, leading to fatigue, cardiovascular disease, and reduced quality of life. Traditional diagnosis requires expensive overnight polysomnography tests conducted in hospitals, making early screening inaccessible for many people.

This project proposes an **AI-powered IoT wearable system** that performs **real-time sleep monitoring at home** using an ESP32 microcontroller and MAX30102 pulse-oximeter sensor. The system continuously records blood-oxygen saturation (SpO_2) and heart-rate signals, uploads them to Firebase cloud storage, and applies machine-learning models such as Random Forest, Decision Tree, and Support Vector Machines (SVM) to detect apnea events.

Mobile and web dashboards provide instant alerts, nightly reports, and long-term trend analysis for proactive healthcare.

---

2. PROBLEM STATEMENT

Current sleep-apnea diagnosis systems suffer from:

- **High Cost:** Clinical sleep studies are expensive and not suitable for frequent screening.
- **Limited Accessibility:** Patients must visit specialized sleep labs.
- **Delayed Detection:** Many cases remain undiagnosed for years.
- **Lack of Continuous Monitoring:** Hospital tests capture only one night of data.
- **Manual Analysis:** Doctors must inspect signals manually, increasing diagnosis time.

---

3. PROPOSED SOLUTION

A **smart wearable screening system** that:

1. Monitors SpO_2 and heart-rate levels throughout the night.
2. Streams sensor data to the cloud in real time.
3. Applies trained ML models to detect abnormal breathing patterns.
4. Calculates apnea severity scores.
5. Sends mobile alerts when dangerous oxygen drops occur.
6. Generates daily sleep-health reports for users and clinicians.

---

4. SYSTEM ARCHITECTURE

The platform is divided into four main modules — similar to the modular approach in the uploaded PDF .

A. The "VitalSense Node" (Data Acquisition Layer)

• Hardware: ESP32 + MAX30102
• Sensors:
– Blood Oxygen Saturation (SpO_2)
– Heart Rate
• Sampling Rate: 50–100 Hz
• Wireless Communication: Wi-Fi / Bluetooth
• Preprocessing on Device:
– Noise filtering
– Moving-average smoothing
– Packet buffering

B. The "AI Clinician" (Decision Engine)

Sleep events are validated through a **multi-model ensemble**:

1. **Signal Layer**
   – Oxygen desaturation detection
   – Heart-rate variability spikes
   – Sudden recovery patterns
2. **Machine Learning Layer**
   – Random Forest
   – Decision Tree
   – SVM
3. **Risk Classification Layer**
   – Normal
   – Mild Apnea
   – Moderate Apnea
   – Severe Apnea

C. The "Cloud Vault" (Storage & Analytics)

• Platform: Firebase Realtime DB / Firestore
• Stores:
– Raw sensor data
– ML predictions
– Event timestamps
– Nightly summaries
• Enables:

– Long-term sleep trend analysis
– Population-level research (anonymized)

D. The "Guardian Alert System" (Notification Module)

• Push notifications via mobile app
• SMS / Email alerts (optional)
• Emergency threshold warnings
• Report generation in PDF format

---

5. TECHNICAL STACK & LIBRARIES

Component	Technology Used	Purpose
Microcontroller	ESP32	Sensor control & Wi-Fi
Sensor	MAX30102	SpO_2 & HR
Backend	Firebase	Cloud storage
ML Training	Python, Scikit-learn	Model development
Data Processing	NumPy, Pandas	Signal analysis
Visualization	React / Flutter	Dashboards
Alerts	Firebase Cloud Messaging	Push notifications

---

6. KEY ALGORITHMS

Oxygen Desaturation Detection Algorithm

```
drop = baseline_spo2 - current_spo2
if drop >= 4:
  event = "Possible Apnea"
```

Heart-Rate Variability Spike Detector

```
hrv = std(rr_intervals)
if hrv > threshold:
  risk_score += 2
```

ML Classification Pipeline

features = extract_features(signal_window)

prediction = model.predict(features)

Apnea Severity Index (AHI Calculation)

ahi = total_events / sleep_hours

---

7. PROJECT OUTPUTS

1. Mobile Dashboard

- Live oxygen graphs
- Sleep timeline
- Risk category
- Alerts history

---

2. Web Portal

- Weekly & monthly analytics
- Downloadable reports
- Doctor review interface

---

3. Emergency Alerts

ALERT: Oxygen Drop Detected

SpO_2: 87%

Risk Level: High

Time: 02:14 AM

---

8. CONCLUSION & FUTURE SCOPE

This project demonstrates how **AI-driven IoT healthcare systems** can enable affordable, real-time sleep-apnea screening at home. By combining wearable sensors, cloud computing, and machine learning, the platform offers early diagnosis, continuous monitoring, and data-driven medical support.
