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Nexus: A Low-Cost Wearable AI Health Companion Using IoT, Edge AI and a Smartphone-Hosted Voice Assistant

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Abstract: *Elderly people and patients with long-term conditions benefit from continuous, low-effort monitoring, yet most commercial health wearables are costly, screen-dependent and passive. This paper presents Nexus (Neural-Enabled eXtended User Support), a low-cost wearable AI health companion built on a three-layer IoT architecture. A wrist-worn ESP32-S3 device senses heart rate, blood oxygen saturation, motion and skin temperature and runs lightweight edge AI. A smartphone acts as the AI gateway and hosts speech recognition, a conversational assistant and speech synthesis. A caregiver interface provides status, alerts, history and location. The device has no display; it uses two-way voice, haptic feedback and a single SOS/TALK button. A proactive, health-focused assistant with short-term memory explains alerts in simple language, and a graded alert scheme with an emergency verification step reduces false alarms before caregivers are notified. The paper describes the requirements, hardware, software and AI design, privacy considerations, development methodology and a planned evaluation. Nexus is a health-monitoring and assistance prototype and is not a medical diagnostic device.*

Keywords: *wearable computing, Internet of Things, edge AI, TinyML, healthcare monitoring, voice assistant, emergency detection, ESP32-S3.*

I. INTRODUCTION

Healthcare is moving from occasional hospital visits towards continuous, home-based monitoring. The Internet of Things (IoT) makes this possible by connecting low-power sensors, mobile devices and cloud services into one system [1]. Wearable sensors in particular can track physical activity and basic physiological signals throughout the day without any effort from the user [2]. For elderly people living alone, and for people with long-term conditions, such monitoring can help family members and caregivers notice problems earlier and respond faster.

Existing consumer wearables still leave several gaps. Many are expensive for the average family. Most rely on a small screen, which is difficult for older users or users with poor eyesight. They are largely passive: they record numbers but rarely speak to the user, explain what a reading means or ask whether the user is all right. Simple threshold alarms also tend to produce false alerts, which causes users to ignore or switch off the device.

This paper presents Nexus, which stands for Neural-Enabled eXtended User Support. Nexus is a low-cost wearable AI companion that senses physiological and activity data, processes it locally with edge AI, talks to the user by voice and uses a smartphone as the AI gateway and caregiver interface.

The main contributions are: (i) a three-layer architecture that keeps the wearable lightweight by moving heavy language processing to the phone; (ii) a display-free interaction model based on voice, vibration and one multi-function button; (iii) a proactive, health-focused conversational assistant that can explain why an alert was raised; (iv) a graded alert scheme with an emergency verification flow that asks the user to confirm before caregivers are notified; and (v) a modular design that can be extended in later versions without redesigning the whole system.

The rest of the paper is organised as follows. Section II states the problem and motivation. Section III reviews related work. Section IV lists the objectives, scope and requirements. Sections V to VIII describe the architecture, hardware, software and AI design, and the mobile application. Section IX discusses privacy, security and ethics. Sections X and XI present the development methodology and the planned evaluation. Sections XII to XV cover applications, advantages and limitations, future scope and the conclusion.

II. PROBLEM STATEMENT AND MOTIVATION

A. Problem Statement

People who are elderly, recovering from illness or living with a long-term condition may need help at any time, but caregivers cannot be present all day. A person may faint, fall, become unwell during sleep or simply feel unwell and not know whether a reading is serious. Devices that could help are often too costly, too complex to operate, or silent when the user most needs guidance. The problem addressed in this work is how to build an affordable wearable that monitors basic health signals continuously, interacts naturally by voice, decides on the device which events deserve attention, and informs caregivers reliably without flooding them with false alarms.

B. Motivation

Three observations motivated the design of Nexus. First, many older users find touch screens and small text hard to use, so a voice-first device lowers the barrier to adoption. Second, a wearable that sends all raw data to a server wastes battery and bandwidth and exposes private information, so local filtering is preferable. Third, a monitoring device is only useful if it is worn, so it must be comfortable, simple and trusted; false alarms damage that trust. These observations lead directly to the design choices of a display-free wearable, edge-level anomaly filtering and a confirmation step before an emergency alert.

III. LITERATURE REVIEW

A. Wearable Health Monitoring

Photoplethysmography (PPG) estimates pulse and blood oxygen saturation by measuring changes in light absorption in the skin, and is the basis of most wrist and finger wearables [3]. PPG is convenient, but its signal is sensitive to motion, skin tone, sensor pressure and ambient light, so readings need filtering and should be interpreted together with activity context. Inertial sensors are widely used for human activity recognition, and surveys of wearable sensing show that accelerometer and gyroscope data can separate common activities and detect abrupt events such as falls [2]. Heart rate variability (HRV) is a well-established indicator of autonomic nervous system activity, and measurement standards were set out by a joint task force in 1996 [4]. Stress estimation from HRV is therefore a reasonable feature for a wellness companion, although values obtained from wrist PPG are only an approximation of clinical ECG-based measurements.

B. IoT Architectures for Healthcare

IoT healthcare systems are commonly described in layers: a sensing layer on the body, a gateway layer that aggregates data and connects to the internet, and an application layer that serves clinicians or caregivers [1]. A smartphone is a natural gateway because most users already own one, and it provides a screen, a fast processor, GPS and mobile connectivity. Nexus adopts this pattern, so the wearable does not need its own cellular modem or GPS receiver in the first version.

C. Edge AI and TinyML

TinyML brings machine learning to microcontrollers with very little memory and power [5]. Frameworks such as TensorFlow Lite Micro [6] and development platforms such as Edge Impulse [7] let developers collect sensor data, train compact models and deploy them on devices like the ESP32 family. Running simple classification and anomaly detection on the device reduces the amount of data that must be sent over the radio, lowers latency and keeps raw sensor data closer to the user.

D. Conversational AI for Health Support

Large language models can hold natural conversations and answer a wide range of questions [8], which makes them attractive for companion devices. They are too large to run on a microcontroller, so a phone or server must host them. They can also produce incorrect statements, so safety-critical decisions should not depend on them alone. Nexus follows this principle: alerts come from deterministic and edge-AI detection logic, while the language model is used to explain, remind and converse.

E. Comparison with Typical Existing Solutions

Table I compares Nexus with two broad categories of existing products in qualitative terms. The comparison describes typical characteristics of each category, not specific brands.

TABLE I
QUALITATIVE COMPARISON WITH TYPICAL SOLUTIONS

Feature	Smartwatch	Emergency pendant	Nexus
Main interface	Touch screen	Single button	Voice + button
Continuous vitals	Yes	Usually no	Yes
Talks to user	Limited	Rarely	Yes, proactive
Explains alerts	Rarely	No	Yes
On-device filtering	Varies	No	Yes
Caregiver app	Varies	Service-based	Yes, multi-user
Cost class	Medium-high	Low-medium	Low

F. Research Gap

Existing work tends to address one part of the problem: sensing, or activity recognition, or a voice assistant, or an alert app. Few low-cost designs combine a display-free wearable, on-device anomaly filtering, a proactive voice companion and a caregiver app in one coherent architecture. Nexus aims to fill this gap with components that are inexpensive and easy to obtain.

IV. OBJECTIVES, SCOPE AND REQUIREMENTS

A. Objectives

The objectives of Nexus are to monitor heart rate, SpO₂, motion and skin temperature trends continuously; to detect unusual patterns and possible emergencies on the device; to let the user talk to the system in both directions by voice; to notify caregivers with the user's location when help is needed; and to keep the total hardware cost low enough for real use. The long-term goal is a design that stays useful for ten to twelve years, with planned upgrades handled as separate versions.

B. Scope

The first version (V1) deliberately limits itself to six core features: heart rate and SpO₂ sensing, activity recognition, edge anomaly detection, voice interaction, emergency verification and an Android caregiver app. Nexus is positioned as a health-monitoring and assistance prototype. It does not diagnose disease, and its skin temperature readings are treated as a contact temperature trend, not as core body temperature. ECG, onboard GPS and cellular connectivity are left for later versions.

C. Requirements

The requirements were derived from the objectives and are summarised in Table II. The non-functional requirements are as important as the functional ones, because a device that is uncomfortable, noisy or unreliable will not be worn.

TABLE II
FUNCTIONAL AND NON-FUNCTIONAL REQUIREMENTS

Type	Requirement
Functional	Measure heart rate, SpO ₂ , motion and skin temperature trend
Functional	Classify activity and flag anomalies on the device
Functional	Two-way voice communication with wake word and button
Functional	SOS by long press; cancel by double press
Functional	Notify caregivers with location after failed verification
Non-functional	Low cost and easily available components
Non-functional	Light, comfortable wrist-worn form without a display
Non-functional	Useful battery life through duty-cycling
Non-functional	Local logging so data survive short outages
Non-functional	Privacy-aware: raw data filtered locally where possible

V. SYSTEM ARCHITECTURE

Nexus uses the three-layer architecture shown in Fig. 1. The wearable collects data and performs light processing. The smartphone provides the heavier AI services and acts as the gateway to the internet. The caregiver interface presents the information to the people who need it.

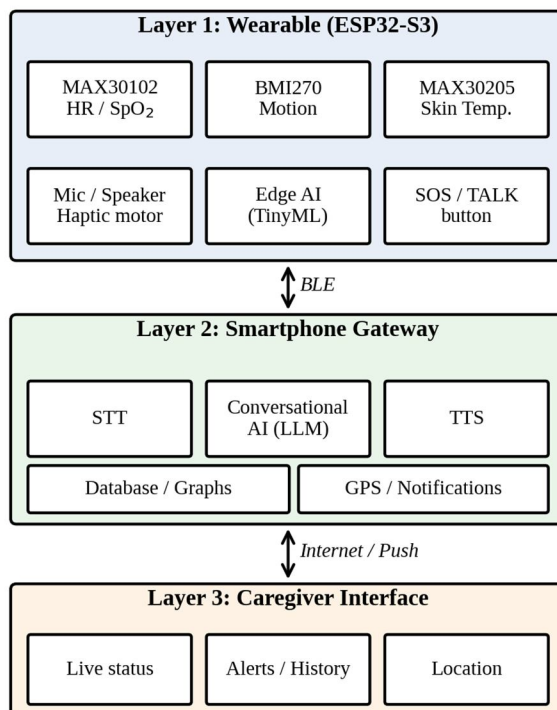


Fig. 1 Three-layer architecture of Nexus: wearable device, smartphone gateway and caregiver interface

A. Wearable Layer

The wearable contains the sensors, a microphone, a speaker, a vibration motor and a single physical button. It filters sensor data, runs small neural models for activity recognition and anomaly detection, and sends compact summaries to the phone over Bluetooth Low Energy (BLE) [14]. It has no display in V1; voice, vibration and the phone dashboard replace it.

B. Smartphone Layer

The phone hosts speech-to-text (STT), the conversational AI, text-to-speech (TTS), the local database, health graphs, GPS and caregiver notifications. Splitting the work in this way keeps the wearable small, cheap and power-efficient, and lets the assistant improve through software updates on the phone without changing the hardware.

C. Caregiver Interface

Caregivers see the current status, receive alerts, browse history and view the user's location during an emergency. Several caregivers can be linked to one user, so that an alert does not depend on a single person being available.

D. Communication Design

The wearable and the phone communicate over BLE because of its low power consumption and universal support on phones. A custom BLE service is planned with separate characteristics for periodic sensor summaries, alert events, control commands from the phone (for example, to change the sampling rate or trigger a vibration) and the audio stream. Sensor summaries are sent as small binary packets at a low rate instead of continuous raw data, which keeps radio use low.

Voice audio needs more bandwidth than sensor summaries. The design therefore uses compressed audio and short utterances, and treats BLE throughput as a risk to be measured during testing. If BLE alone proves insufficient, the ESP32-S3's Wi-Fi radio can be used to transfer audio while BLE continues to carry control and sensor data.

VI. HARDWARE DESIGN

The hardware is chosen for low cost, wide availability and good community support. Table III lists the main components and their roles.

TABLE III
MAIN HARDWARE COMPONENTS OF NEXUS

Module	Component	Function
Controller	XIAO ESP32-S3 Sense	Processing, BLE, edge AI, integrated microphone
HR / SpO ₂	MAX30102	PPG-based pulse and oxygen saturation, worn on underside of wrist unit
Motion	BMI270	Activity recognition, fall-like motion
Temperature	MAX30205	Skin / contact temperature trend
Audio out	MAX98357A + 4 Ω speaker	Class-D amplifier and voice playback
Haptics	3 V coin motor with NPN driver	Vibration alerts; flyback diode protects the circuit
Input	Tactile SOS/TALK button	Wake, SOS and cancel
Power	3.7 V LiPo with protection, slide switch	Battery operation and power control
Debug	Optional 0.96" OLED	Development use only
Mechanical	3D-printed case, silicone/Velcro strap	Wrist-worn enclosure

A. Controller and Sensors

The ESP32-S3 provides dual-core processing, Bluetooth 5 (LE) and vector instructions that help neural network inference [12]. The XIAO ESP32-S3 Sense board was selected because it includes a digital microphone on the same small board, which avoids extra wiring [15]. The MAX30102 integrates the LEDs, photodetector and signal conditioning needed for pulse oximetry [9], the BMI270 is a low-power inertial measurement unit designed for wearables [10], and the MAX30205 is a contact temperature sensor [11]. The three sensors share an I²C bus with pull-up resistors, as shown in Fig. 2.

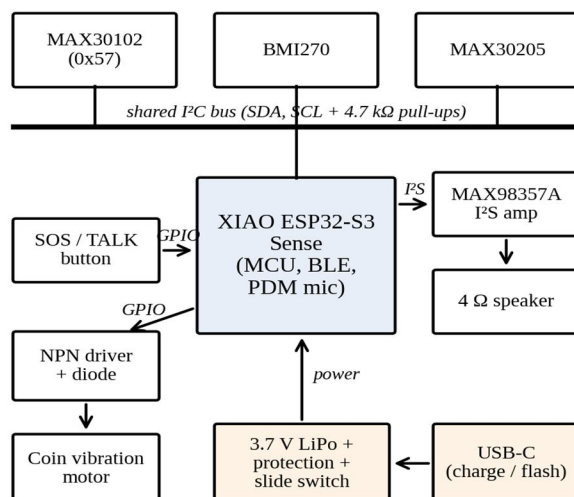


Fig. 2 Hardware interconnection of the Nexus wearable

B. Audio and Haptics

The speaker is driven through an I²S class-D amplifier [13], which gives clear voice output from a small 4 Ω speaker without a large analogue circuit. The vibration motor draws more current than a microcontroller pin should supply, so it is switched by an NPN transistor with a base resistor, and a flyback diode across the motor protects the transistor from voltage spikes when the motor switches off.

C. Input and Interaction

A single button carries three functions: a short press wakes the assistant, a long press starts an SOS, and a double press cancels an emergency. Using one button keeps the device simple for older users, who do not have to remember several controls. Vibration patterns of different lengths tell the user what the device is doing even when the environment is too noisy for speech.

D. Power Management

The device is powered by a 3.7 V lithium-polymer cell with a protection circuit and a slide power switch, and it can be charged and programmed through USB-C. Battery life is a key constraint for any wearable. Nexus addresses it through sensor duty-cycling, keeping the radio in low-power connection modes, sending summaries instead of raw data and waking the audio path only when needed. The actual runtime will be measured on the prototype.

E. Enclosure and Placement

The electronics are housed in a 3D-printed wrist enclosure held by a 20 mm silicone or Velcro strap. The MAX30102 is placed on the underside of the enclosure so that it touches the skin of the wrist, and the contact temperature sensor is located near it. The speaker and microphone openings are placed on the upper and side faces so that clothing does not block them. Using a printed case also allows the shape to be adjusted quickly during prototyping. No onboard GPS is included in V1; location is taken from the smartphone only when an emergency occurs, which saves cost and battery.

VII. SOFTWARE AND AI DESIGN

A. Wearable Firmware

The firmware is first developed in the Arduino IDE for fast prototyping and can later move to ESP-IDF for finer control of power and real-time tasks. It samples the sensors, applies filtering, runs the edge models and exchanges data with the phone over BLE. Sensor duty-cycling is used to extend battery life: sensors are sampled at a lower rate when the user is at rest and more often when activity or an anomaly is detected.

B. Data Processing Pipeline

Sensor data pass through the pipeline shown in Fig. 3. Raw PPG, inertial and temperature samples are first filtered to remove noise and obviously invalid values, for example when the sensor loses contact with the skin. The filtered stream is cut into short windows, and features such as signal energy, peak intervals and variability are extracted. The features feed the edge models, and the results are combined by alert-level logic that decides what, if anything, should be reported to the phone.

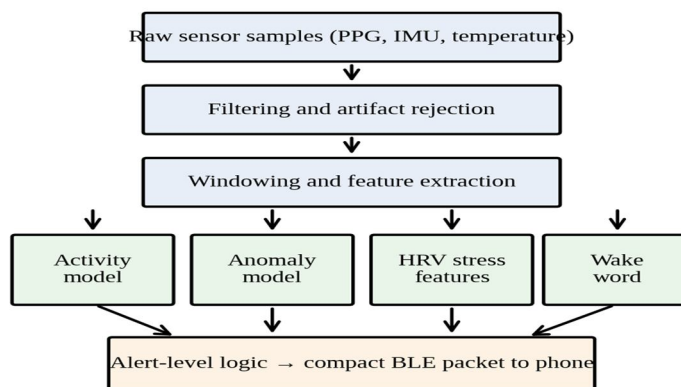


Fig. 3 On-device data processing pipeline from raw samples to compact BLE packet

C. Edge AI Models

- 1) **Activity Recognition:** Windows of accelerometer and gyroscope data are converted into features and classified by a compact neural network, for example into resting, walking and abrupt-impact classes. The activity label gives context to the heart rate reading: a high pulse during walking is normal, while the same pulse at rest may not be.
- 2) **Anomaly Detection:** Heart rate and SpO₂ are compared against the user's own baseline and the current activity. Only unusual patterns are flagged, which reduces false alarms and the amount of data transmitted. Models can be built with TensorFlow Lite Micro or Edge Impulse [6], [7].
- 3) **HRV-Based Stress Detection:** Beat-to-beat intervals from the PPG signal are used to compute simple HRV features [4], which give an approximate stress indicator for wellness feedback. This is not presented as a clinical measurement.
- 4) **On-Device Wake Word:** A small keyword-spotting model on the wearable listens for the wake word, so that audio is sent to the phone only after the user calls the assistant. This saves power and improves privacy.

D. Model Development Workflow

Models are developed in four steps. Data are collected from the prototype while volunteers perform labelled activities such as resting, walking and simulated abrupt movements. The data are cleaned and split into training and test sets. A small network is trained and then quantised to reduce its size and make it fit the microcontroller's memory. Finally, the model is deployed to the device and tested on data that were not used for training. Because a model trained on a few people may not generalise, the baseline for anomaly detection is made personal and adapts to each user over the first days of use.

E. Graded Alert Scheme

To avoid treating every unusual reading as an emergency, Nexus uses four alert levels (Table IV). Lower levels lead to quiet, friendly feedback, and only the highest level contacts caregivers.

TABLE IV
GRADED ALERT LEVELS

Level	Condition	Response
0	Normal readings	Log data only
1	Mild unusual trend	Assistant mentions it gently and suggests rest or water
2	Persistent anomaly or fall-like motion	Vibrate and ask the user by voice if they are all right
3	No reply, or SOS pressed	Notify caregivers and share GPS location

F. Voice Interaction

Voice is the main interface of Nexus, and the pipeline is shown in Fig. 4. After the wake word or a button press, the wearable captures audio and streams it to the phone over BLE. The phone converts speech to text, passes the text and recent context to the language model, converts the reply to speech and sends the audio back to the wearable speaker.

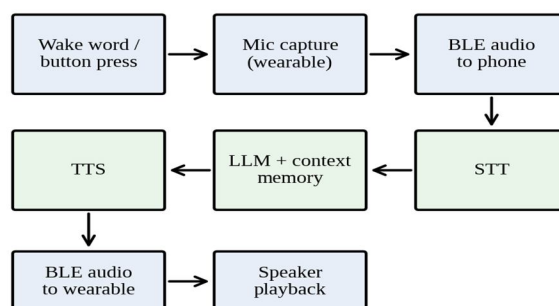


Fig. 4 Two-way voice interaction pipeline between the wearable and the smartphone

G. Conversational Assistant

The assistant is designed as a proactive companion instead of a simple question-and-answer tool. It speaks up about noteworthy readings without being asked, keeps short-term memory of the day (for example, that the user slept badly) so that later readings are interpreted with that context, and offers anticipatory suggestions, such as a stretching routine after a step goal is reached. It uses a warm and positive tone. It can answer general questions, but its main focus stays on health and fitness. An *explain the alert* feature tells the user in plain language why an alert was triggered, not only that it was.

To keep the system safe, the language model does not decide whether an emergency exists. That decision comes from the edge detection logic and the user's own confirmation. The assistant is also instructed to avoid diagnosis and to suggest contacting a doctor for medical concerns.

H. Emergency Verification

An emergency can start automatically, when the edge model detects a serious anomaly, or manually, with a long press of the SOS button. Nexus then asks the user by voice whether they are all right (Fig. 5). If the user answers, or double-presses the button, the alert is cancelled and the event is logged. If there is no response within the timeout, the phone notifies the caregivers and shares its GPS location. This confirmation step is intended to reduce false alarms while still reaching help quickly when the user cannot respond.

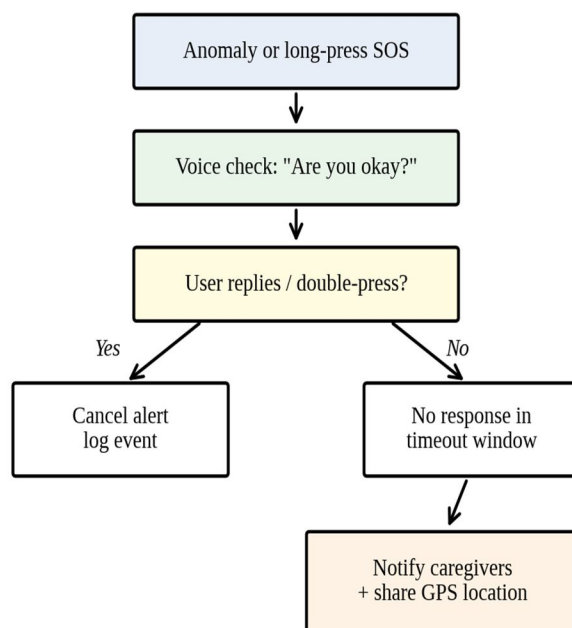


Fig. 5 Emergency verification flow from detection to caregiver notification

I. Offline Resilience

Data are logged locally and synchronised when connectivity returns, so that a short network outage does not lose information. If the wearable loses its connection to the phone, it keeps logging, and it can still give vibration feedback for a local alert. When the connection is restored, the stored events are uploaded in order.

VIII. MOBILE APPLICATION AND CAREGIVER INTERFACE

A. Application Design

The Android application is developed in Android Studio using Kotlin. It manages the BLE connection, the voice services, the dashboard and graphs, and caregiver notifications [16]. Data are stored with SQLite on the device and, where cloud sync is needed, with Firebase [17]. The main screens are a home dashboard that shows the current status in simple colours, a history view with graphs of heart rate, SpO₂, activity and temperature trend, an alerts view, and a settings screen for caregivers, wake word and notification preferences.

B. Multi-User Caregiver Mode

More than one caregiver can be linked to a user. When an emergency occurs, every linked caregiver receives the alert and the user's location, and the first person to acknowledge it is shown to the others, so that the response is not duplicated or missed. Caregivers can see trends and past events but cannot listen to the user's conversations with the assistant unless the user chooses to share them.

C. Accessibility

Because the intended users may be elderly, the interface uses large text, high contrast and simple language. The wearable itself needs no screen, and the assistant can repeat or rephrase an answer when asked.

IX. PRIVACY, SECURITY AND ETHICAL CONSIDERATIONS

A health companion handles sensitive personal data, so privacy and security are part of the design and not an afterthought. Raw sensor data are processed on the wearable whenever possible, and only summaries and events are sent to the phone. The wake-word model prevents continuous audio streaming. Communication between the wearable and the phone is paired and encrypted using the standard BLE security features [14], and cloud storage, when used, is protected by user authentication and access rules.

Users and caregivers should give clear consent about what is shared, and the user should be able to review and delete stored data. Any real-world deployment in India would also need to follow applicable data-protection law, such as the Digital Personal Data Protection Act, 2023. Ethically, the system must not overstate its abilities: Nexus is a monitoring and assistance aid, it does not diagnose, and its advice is general wellness guidance. The assistant keeps a positive tone, but it must still report a worrying reading honestly and encourage the user to seek medical help when appropriate.

X. DEVELOPMENT METHODOLOGY

The project follows a 20-week build plan that proceeds from sensing to integration (Table V). Hardware modules are tested one at a time on a breadboard before they are combined, and software is developed in increments so that each stage produces a working demonstration.

TABLE V
TWENTY-WEEK DEVELOPMENT PLAN

Phase	Weeks	Activities
1	1–8	Sensor interfacing, signal preprocessing, data collection and model training
2	9–12	BLE link, Android app, voice input and output
3	13–16	AI assistant, emergency logic, caregiver notifications
4	17–20	PCB and enclosure, system testing, report

The team's skills are balanced across hardware, programming and AI/ML, so each phase can be shared: hardware members handle the circuit, sensors and enclosure, programming members handle firmware and the Android application, and AI members handle data collection, model training and the assistant. Risks are managed by building the minimum working path first (sensor to phone to alert) and adding the assistant and extra features afterwards.

XI. TESTING AND PROPOSED EVALUATION

A. Planned Metrics

Because the prototype is still under development, this paper does not report experimental results. The evaluation planned for the finished prototype is summarised in Table VI. Each measurement will be compared with a suitable reference device or with ground truth labelled during testing, and results will be reported in later work.

TABLE VI
PLANNED EVALUATION PARAMETERS

Parameter	Method
HR / SpO ₂ accuracy	Compare with a commercial pulse oximeter at rest and during light activity
Activity recognition	Accuracy and confusion matrix on labelled test sessions
Anomaly detection	Precision, recall and false-alarm rate on simulated events
Voice latency	Time from end of speech to start of spoken reply
Alert delivery	Time from SOS or timeout to caregiver notification
BLE reliability	Packet loss and reconnection behaviour at typical distances
Battery life	Runtime with and without sensor duty-cycling
Usability	Feedback from users and caregivers using a short questionnaire

B. Test Scenarios

Besides numerical metrics, the complete system will be tested with scenarios that reflect real use (Table VII). Simulated events will be used for emergencies; no test will put a person at risk.

TABLE VII
PLANNED SYSTEM TEST SCENARIOS

Scenario	Expected behaviour
Normal day	Data logged, assistant gives occasional friendly tips
Poor sleep reported	Later readings are interpreted with that context
Simulated abrupt fall	Vibration and voice check; alert if no reply
False alarm	User replies or double-presses; alert cancelled
SOS long press	Caregivers notified with location
Phone out of range	Wearable logs locally and syncs on reconnection
Sensor off wrist	Invalid data rejected; no false alert

XII. APPLICATIONS AND USE CASES

The first target group is elderly people who live alone or spend much of the day without family nearby. The assistant can remind them to move, drink water or rest, and caregivers can check the trends from a phone. A second group is people recovering at home after illness or surgery, for whom a family member wants simple reassurance that readings look normal. A third is general wellness and fitness users who like a voice companion that encourages them to reach their daily goals. The same architecture can also be adapted for workers in demanding environments or for supervised group care, because the caregiver interface supports several users and several caregivers.

XIII. ADVANTAGES AND LIMITATIONS

A. Advantages

Nexus uses inexpensive, easily available parts. Its voice-first, display-free design suits older users. Edge filtering lowers radio traffic and reduces false alarms. Putting the language model on the phone keeps the wearable simple and allows the assistant to be improved without new hardware. The modular structure makes later upgrades straightforward.

B. Limitations

Wrist PPG readings are affected by motion and fit, and the skin temperature is only a trend, not core body temperature. The conversational assistant needs the phone and, for the language model, usually an internet connection. V1 has no onboard GPS and depends on the phone for location. Battery life is limited by the small cell and by audio streaming. Language models can make mistakes, which is why they are not used for emergency decisions. Finally, Nexus is not clinically validated and must not be used to diagnose or treat any condition.

XIV. FUTURE SCOPE

A second version (V2) could add ECG, onboard GNSS, a better PPG sensor, cellular connectivity, more advanced TinyML models, multilingual offline speech recognition, a larger battery and a custom flexible PCB. These upgrades would make the device independent of the phone for location and basic voice commands. A third version (V3) could aim at medical-grade validation, collaboration with clinicians and certified hardware, which is the necessary step before any clinical use.

XV. CONCLUSION

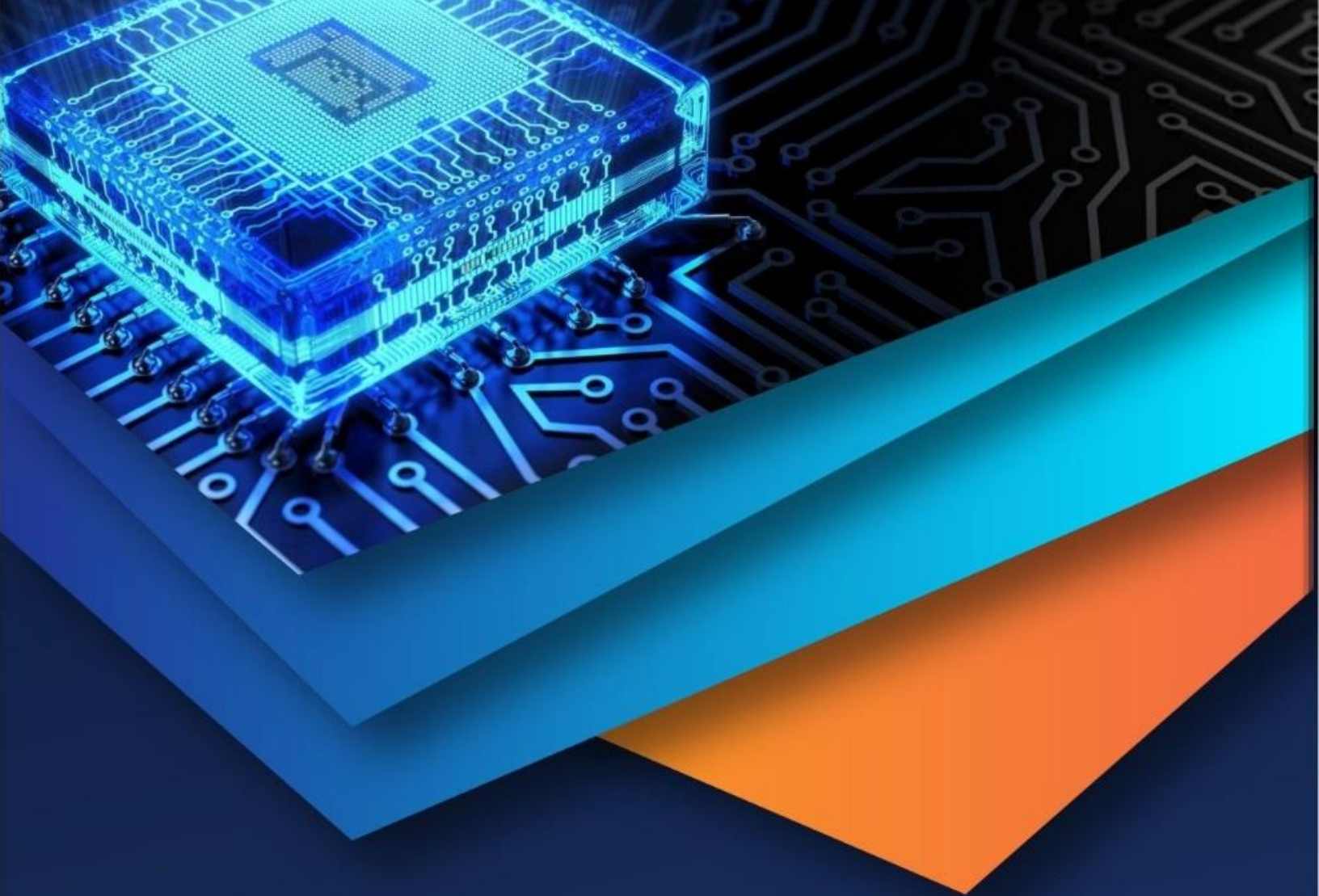
This paper presented Nexus, a low-cost wearable AI health companion based on a three-layer IoT architecture. By combining a display-free wrist device, on-device anomaly filtering, a smartphone-hosted proactive voice assistant and a caregiver app, Nexus addresses the cost, accessibility and passivity problems of many existing wearables. The design keeps safety-critical decisions in deterministic and edge-AI logic, uses a graded alert scheme and adds a confirmation step before alerting caregivers. The next stage of the work is to complete the prototype, carry out the planned evaluation and report measured results.

XVI. ACKNOWLEDGMENT

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