LLM-Empowered Wearables:
Architecture, Applications and Challenges

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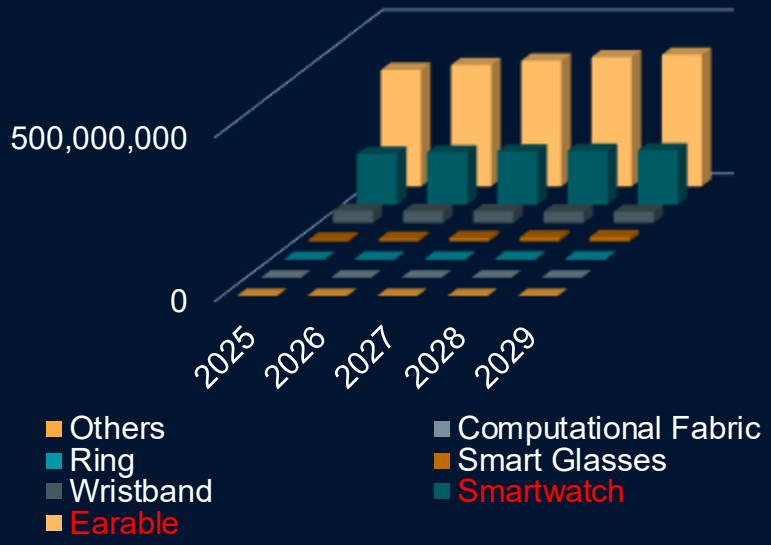
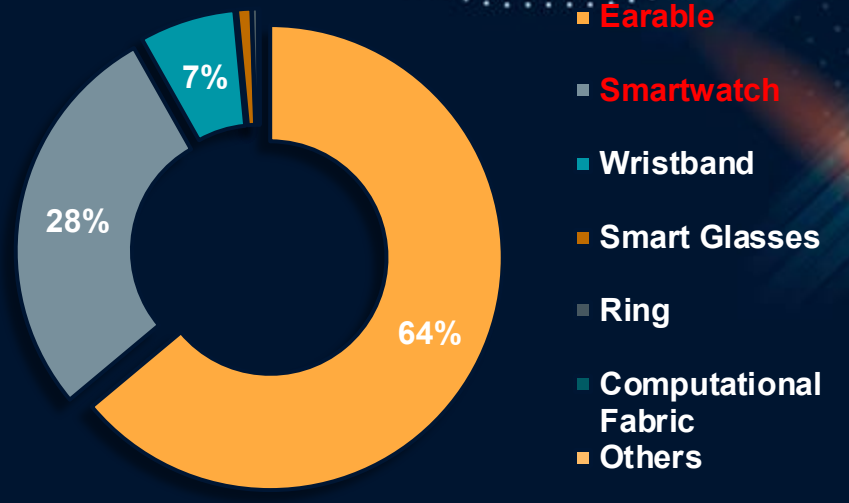
- Wearable Device Market
- Wearables + Multi-modal LLM
- Applications
- Challenges

Wearable Device Market Overview





Source: IDC https://www.idc.com/promo/wearablevendor/

Trends of Wearable Technologies

AI-Integrated

Devices are becoming increasingly intelligent, enabling real-time health analytics.

Health Apps

Everyday devices now support fitness tracking, disease prevention, and early warning.

Diversified Sectors

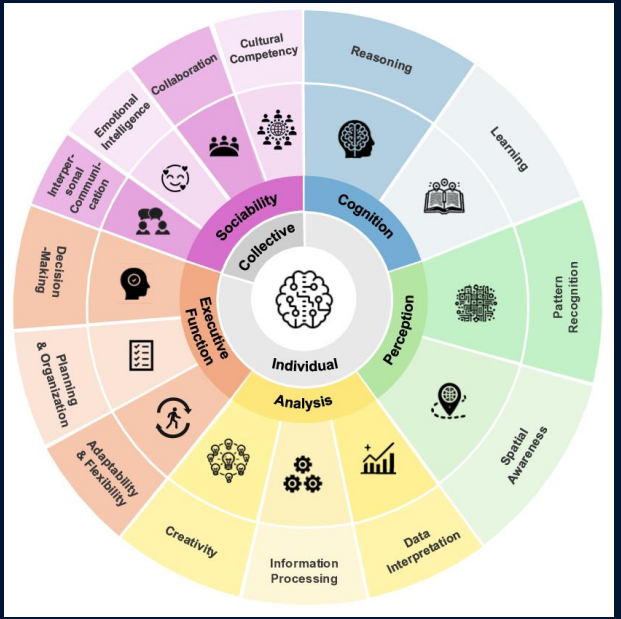
Rapid growth in smart earphones and smart glasses.

Stable Growth

Overall market growth projected at **4.1% in 2025**

Large Language Models

- Trained on vast text corpora
- Powerful language understanding/generation
- The first “truly general-purpose” AI technology:
  - Dialogue, translation, and creative expression
  - Complex reasoning and linguistic tasks



LLM Capability Spectrum

Multi-modal LLM (MLLM)

01

Multimodal Fusion

Heterogeneous Modalities
Generate Missing Data

02

Breaking Device Barriers

Cross-Device Data Sharing

03

Empowering Consumer-Grade Devices

General Knowledge
Enhance Everyday Devices

04

Personalized User Interaction

AI Agents with Personal
Sensor Data

Vision: Wearable + MLLM — Empowering Everyday Life

Elderly Health and Companionship

Fall Detection, Health Monitoring (Mobicom24, IMWUT25)

"You seem to have walked less than usual today. I suggest taking a light walk this afternoon."

Social Assistance and Productivity

Real-time Cross-lingual Communication, Task Reminder/Summarization (IMWUT25)

"The other party said, 'Let's meet next Tuesday.' I've added it to your calendar"

Mental Health Management

Daily Conversations, Journaling, Emotion Analysis (Product: Nuna)

"You appear generally in good spirits today after spending time chatting with friends."

MLLM Deployment on the Edge

On-Device Deployment:

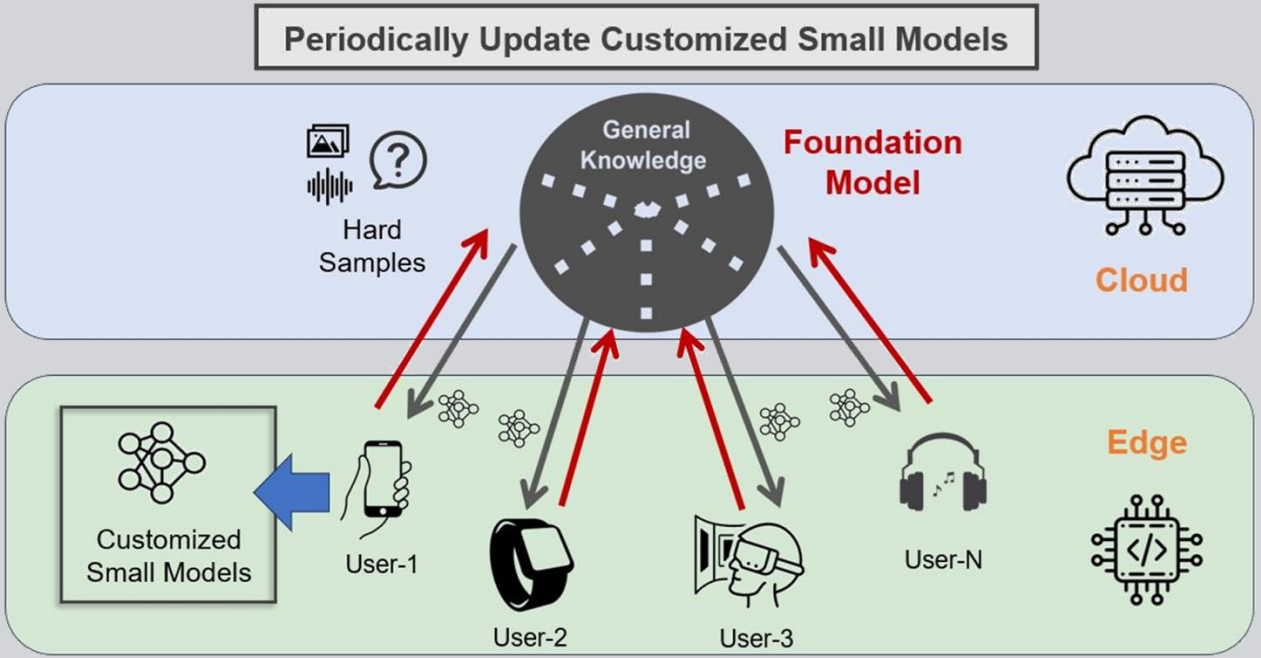
- Model runs locally
- Data stays private and real-time
- Limited computing resources

Edge-Cloud Collaboration:

- Real-time tasks at the edge
- Training & optimization in the cloud
- Efficient, seamless synergy

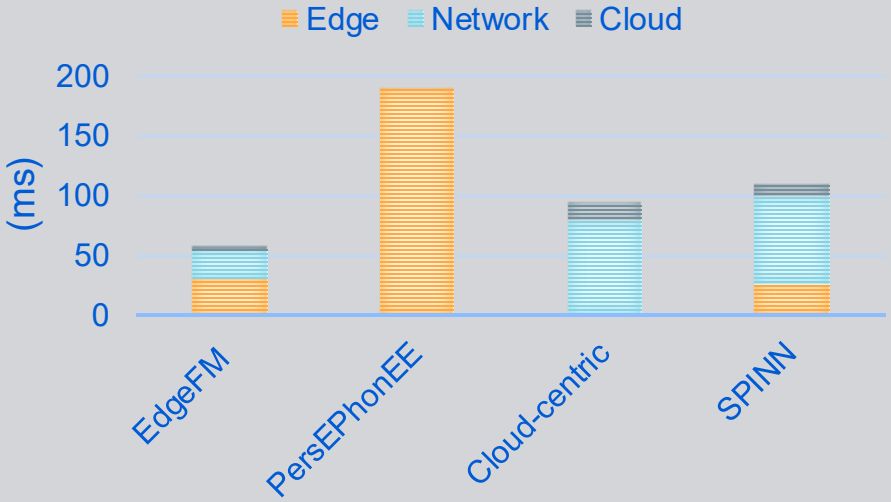
EdgeFM: Enable Open-set Learning on the Edge

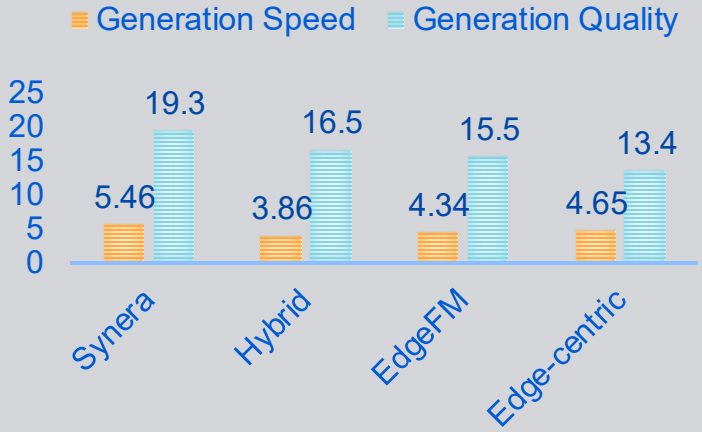
- **Continuous interaction** between cloud-side FMs and edge-side specialized models
- **Dynamic model routing** considering both sensor data uncertainty and network speed



[1] Bufang Yang, Lixing He, Neiwen Ling, Zhenyu Yan, Guoliang Xing, Xian Shuai, Xiaozhe Ren, Xin Jiang. "EdgeFM: Leveraging Foundation Model for Open-set Learning on the Edge." Proceedings of the 21th ACM Conference on Embedded Networked Sensor Systems. SenSys'23.

Results



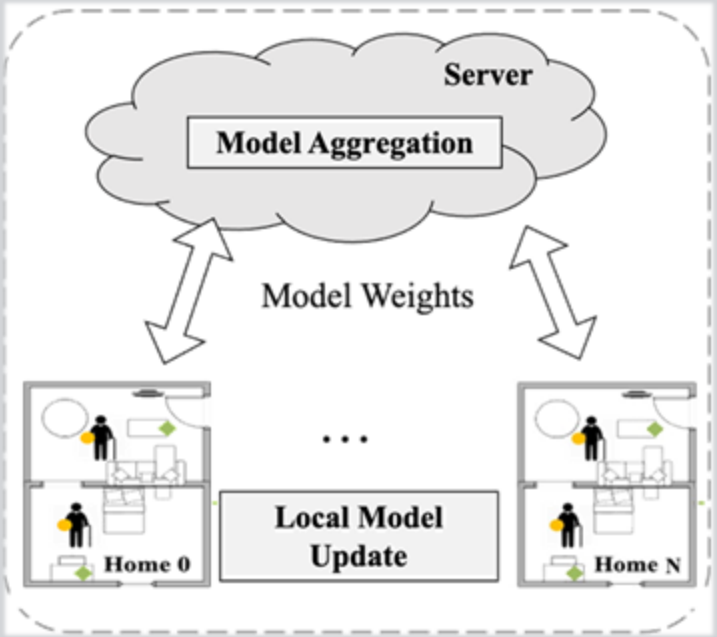


- 3 public datasets and 2 real-world datasets
- Reduce the **3.2x** end-to-end latency
- **34.3%** accuracy increase

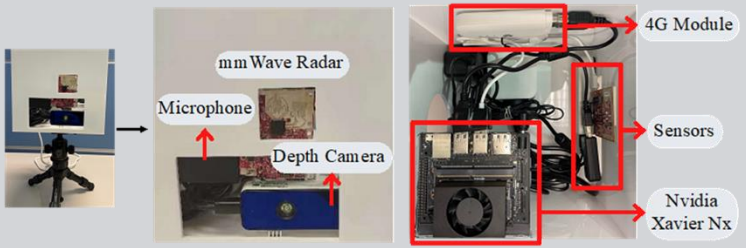
- Inference cost reduced by **8.2-16.5%**
- **5.47×** Accuracy increase

ADMarker: Early screening for cognitive decline

- Multi-modal sensors
- new machine learning
- End-to-end AD digital biomarkers detection

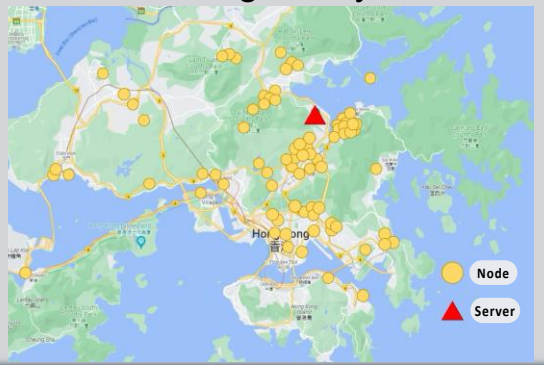


Multi-modal hardware systems



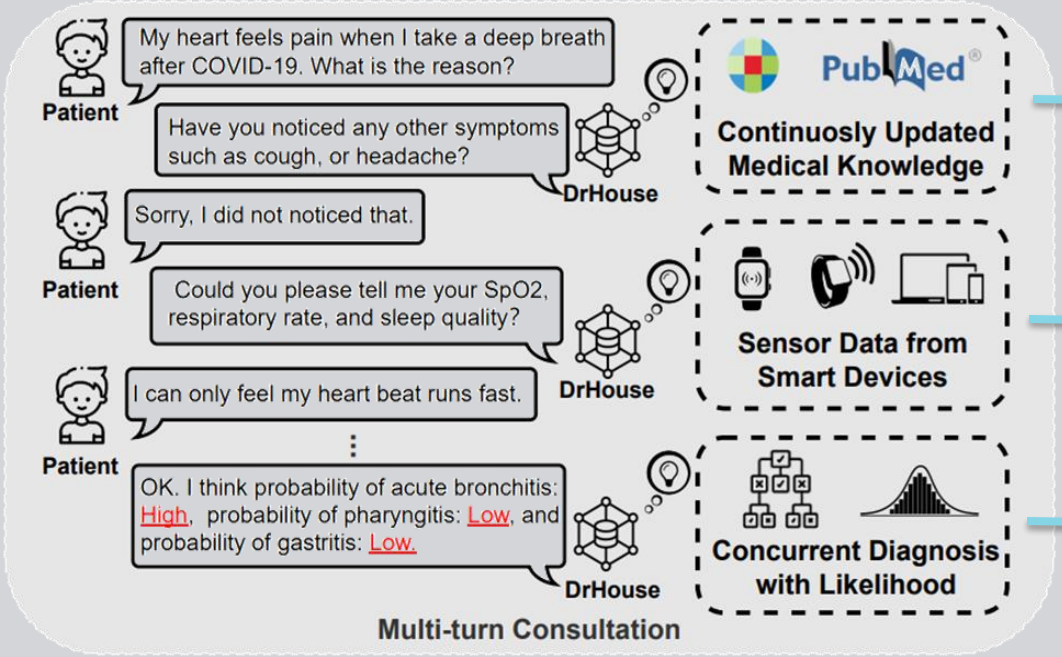
Clinical deployment

- 200+ older participants
- AD, MCI, and cognitively normal



[1] X. Ouyang, et. al. ADMarker: A Multi-Modal FL System for Monitoring Digital Biomarkers of Alzheimer's Disease, MobiCom'24.

DrHouse: LLM + Sensor data for diagnostic reasoning



Up-to-date expert knowledge

Objective data from **wearable sensors**

Follow-up questioning, assess multiple diagnoses in parallel

[1] Bufang Yang, et. al. DrHouse: An LLM-empowered Diagnostic Reasoning System through Harnessing Outcomes from Sensor Data and Expert Knowledge. " Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, (IMWUT/UbiComp 2025).

SocialMind: LLM+AR glasses for proactive social assistance

- Multimodal, human-like perception
- Real-time, proactive social assistance

Live Social Interatcions

Multi-modal Sensor Data (Audio, Video, Head Motion)

Human-like perception

Implicit persona adaptation

LLM Reasoning

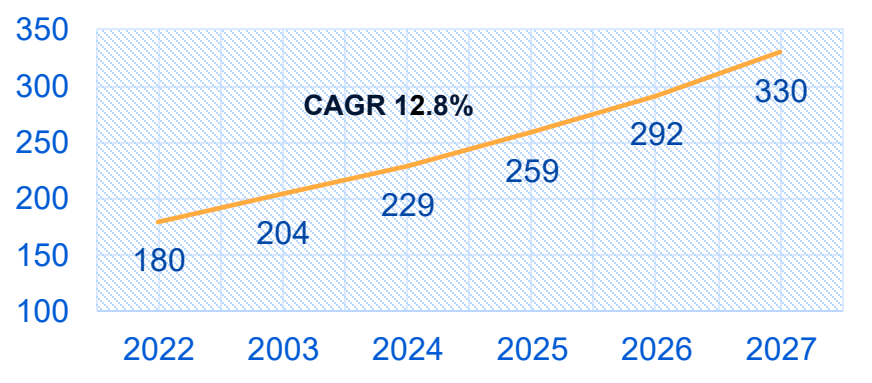
In-situ Social Suggetsions (Points, Examples)

[1] Bufang Yang, et. al. SocialMind: LLM-based Proactive AR Social Assistive System with Human-like Perception for In-situ Live Interaction. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, (IMWUT/UbiComp 2025).

Nuna: LLM-empowered Pendant for Mental Health

- **Global:** Over **1 billion** people suffer from mental disorders [1]
- **U.S.:** Market size projected to reach **USD 110 billion** by 2024 [2]

Global Mental Health Market Size (2022–2027, USD Billion)



[1] World Health Organization. (2025, September 2). *Over a billion people living with mental health conditions – services require urgent scale-up*. WHO.
[2] IMARC Group. (2024). *U.S. Mental Health Market Size & Growth Forecast to 2033*. Retrieved from IMARC Group website.

Nuna Innovations

THiNGX

01 Multimodal Emotion Recognition

- Data Fusion
- Personalized Physiology
- Real-time Inference

02 Acoustic Event Extraction

- Scene Recognition
- Context Modeling
- Voice Enhancement

03 mmWave Vital Sensing

- Near-field Coupling
- Micro-motion Accuracy
- Motion Suppression

04 RAG-based Perception

- Multimodal Retrieval
- Real-time Indexing
- Illusion Suppression

05 Edge Large Language Model

- Model Compression
- Multi-task Handling

Challenges for LLM-empowered Wearables

01

Low Data Quality

- Data loss during non-wearing periods [1]
- Motion artifacts by sensor displacement [2]

02

Data Islands

- Poor data sharing & compatibility across devices

03

Health Equity

- Expensive specialized devices
- Limited accessibility

04

Poor User Experience

- Unfriendly interface and interaction
- Accessibility challenges for older adults [3]

[1] Böttcher et al. Data quality evaluation in wearable monitoring. Scientific Reports, 2022.
[2] Van Der Donckt et al. Mitigating data quality challenges in ambulatory wrist-worn wearable monitoring through analytical and practical approaches. Scientific Reports, 2024.
[3] Bertolazzi et al. Barriers and facilitators to health technology adoption by older adults with chronic diseases: an integrative systematic review. BMC public health, 2024.

CUHK AIoT Lab

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Email: **hello@thingx-tech.com**

AI-Based Emotional Support Grounded in Psychotherapy

THiNGX

Core Function —— Emotion Detection

Following Cognitive–Behavioral Therapy, *a first-line treatment for depression, anxiety, insomnia, and other emotional disorders.*

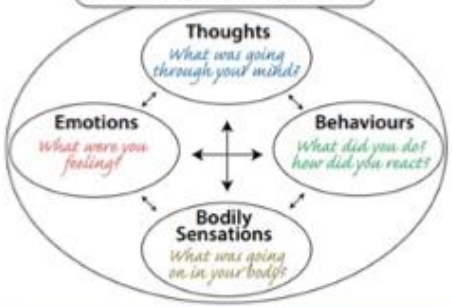
Your early experiences

↓ influence

The development of your beliefs about yourself, the world, your future

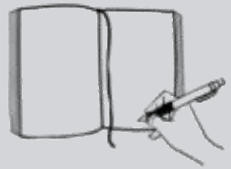
↓ Which affect how you perceive

Situations In The Here-And-Now



Meditation & Thoracic Vibration Stimulation Function

Automatic Journaling



Wearable + MLLM Architecture

- Embedded Computing
- Energy Optimization
- Real-Time Data Capture

- On-Device Models
- Edge-Cloud LLM

- Health
- Social/Lifestyle

Use Cases for Wearable + MLLM

Case 1: Sleep Monitoring

Smart watch for sleep

"Based on your heart rate, we recommend going to bed early and avoiding caffeine"

Case 2: Fitness Guidance

Combining earbuds with gait monitoring

"Your running posture needs adjustment, maintain a rhythm of 80 steps/minute"

Case 3: Early Detection for Diseases

Detect cardiac arrhythmia through glasses

"Your heart rate may be abnormal, we recommend consulting a doctor"