Multi-sensor AI smart health guardian system Technical White Paper

For medical institution managers, pension service providers and smart health investors

1. Overview

1.1 Background and Challenges

The global trend of population aging is becoming increasingly serious, with growing demands for home-based elderly care and medical wellness. According to the U.S. Census Bureau, by 2030, one-fifth of the U.S. population will be of retirement age. In China, the population aged over 60 reached 280 million (2022 data), making home-based elderly care a mainstream option.

Limitations of traditional health monitoring methods:

- **Wearable Devices**: Rely on users to actively wear them; elderly users have low compliance; require frequent charging.
  Our Solution: Fully contactless monitoring, no need to wear any devices, significantly increases usage among the elderly.
- **Environmental Sensors**: Limited monitoring dimensions; weak data integration.
  Our Solution: Multisensor fusion technology for comprehensive health data and holistic profiling.
- **Traditional Video Monitoring**: Raises privacy concerns; performance drops in low-light environments.
  Our Solution: Millimeter-wave radar provides 24/7 monitoring and complete privacy protection.
- **Periodic Checkups**: Data is not continuous and cannot reflect real-time health conditions.
  Our Solution: 24/7 continuous monitoring with health trend analysis and real-time alerts.

1.2 System Objectives

The system integrates millimeter-wave radar technology, optical sensing technology, artificial intelligence and edge computing to create a comprehensive health protection solution and create the following values for medical institutions and elderly care service providers:

- **Improve Care Quality:** Contactless and wearable-free monitoring increases compliance.
- **Reduce Operational Costs:** Less manpower required; about 30% lower per-bed care cost.
- **Enhance Safety:** 24/7 multidimensional physiological monitoring with a 92% emergency alert success rate.
- **Ensure Privacy:** No video collection; complies with GDPR, HIPAA, and other regulations.
- **Boost ROI:** Easy to deploy; saves nearly CNY 6,000 annually per bed.

Applicable scenarios: home care, hospital wards, health care institutions, special industries and other scenarios

> **Industry leadership**: Our team has more than many years of experience in millimeter-wave radar technology research and development and in-depth research in the field of AI medical care, and has successfully completed testing and deployment in many tertiary hospitals and high-end elderly care institutions at home and abroad, establishing a leading position in the industry.

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2. Technical Architecture

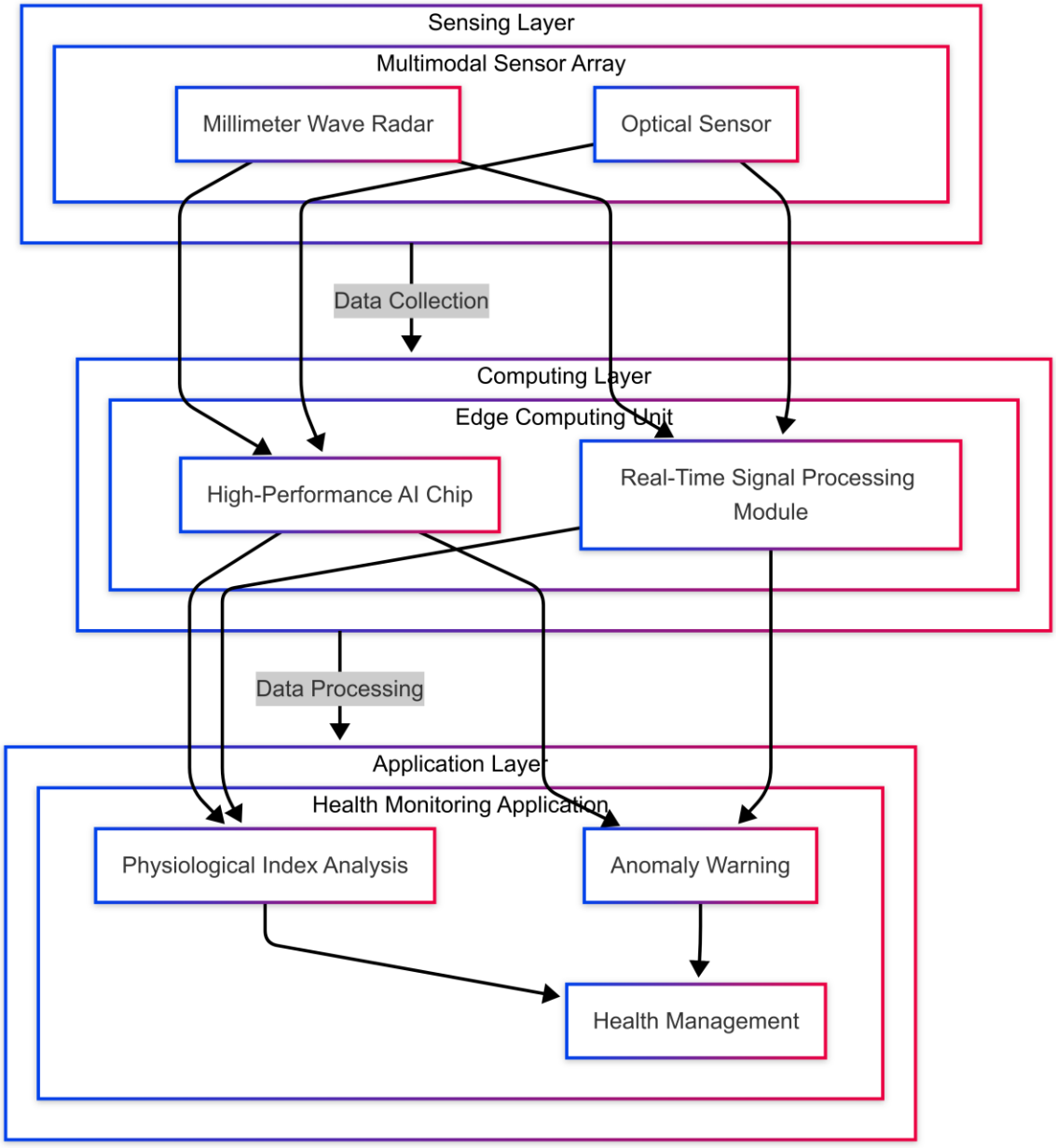
2.1 System Architecture Overview

The system uses a three-layer architecture:

1. Perception Layer: Multimodal sensor array (Millimeter-wave radar, optical sensors, microphone arrays)

2. Computing Layer: Edge computing units (high-performance AI chips, real-time signal processors)

3. Application Layer: Health monitoring apps (physiological analysis, anomaly alerts, health management)



2.2 Core Technology Modules

2.2.1 Millimeter-wave Radar Technology

Uses 4T4R FMCW radar at 60GHz with the following specs:

parameter	specification	advantage
Detection range	6-8 meters	Far more than similar products on the market (3-4 meters)
Distance resolution	4cm	The target location can be pinpointed
Velocity resolution	0.1m/s	Detects small movements

Angular resolution	1°	Precise positioning of multi-target angles
Beam width	120°	Wide coverage
Refresh rate	50Hz	Fast real-time response

How FMCW radar works:

1. The transmitter emits an FM signal with a linear change in frequency with time

2. The signal is reflected by the target and received

3. Mixing the transmitted signal with the received signal by means of a mixer

4. Generate an intermediate frequency (IF) signal with a frequency proportional to the target distance

5. IF signals are processed by FFT (Fast Fourier Transform) algorithm

6. Extract information such as distance, speed, angle, etc

Terminology explanation: FMCW (Frequency Modulated Continuous Wave) is a radar transmission mode that achieves high-precision ranging through frequency modulation; FFT (Fast Fourier Transform) is a mathematical algorithm that converts time-domain signals into frequency-domain signals.Signal processing flow:

raw radar signal → distance FFT → velocity FFT → angle FFT → CFAR detection → target tracking → feature extraction → physiological parameter calculation

Advantage analysis:
- Strong penetration: It can penetrate non-metallic materials such as clothing and bedding to solve the limitations of traditional monitoring equipment
- All-weather: not affected by environmental factors such as light and temperature, to ensure 24/7 continuous monitoring
- Privacy protection: No video images are captured, user privacy is protected, and regulatory requirements are met
- Multi-target: It supports the simultaneous monitoring of multiple targets, which is suitable for multi-person living environments

2.2.2 Optical sensing technology

Utilizes remote photoplethysmography (rPPG) to detect micro blood volume changes via high-resolution optical sensors.

Technical Parameters:
- Optical sensor resolution: 2688×1520

- Frame rate: 60fps

- Spectral range: visible light + near-infrared (400-900nm)

- Processing algorithm: CHROM (colorimetric decomposition algorithm), POS (planar orthogonal spectrum algorithm), adaptive filtering

Signal processing flow:
video acquisition→ detection and tracking, → ROI (region of interest) extraction, → color space conversion, → time domain filtering, → frequency domain transformation, → main frequency extraction, → heart rate calculation

Key technological innovations:
- Multi-ROI adaptive selection: dynamically selects the optimal ROI region according to the signal-to-noise ratio to solve the problem of poor stability of traditional rPPG algorithms

- Motion compensation algorithm: effectively reduce the impact of head movement on signal quality and improve the accuracy in practical application scenarios

- Ambient Light Adaptive Correction: Responds to signal deviations under different lighting conditions to ensure reliable monitoring around the clock

2.2.3 AI Intelligent Analysis Technology

Based on the deep learning framework, the system builds a multi-level AI analysis model:

1. **Feature Extraction Layer:**
    - CNN for spatial features
    - LSTM for time series
    - Autoencoders for denoising

2. **Parameter recognition layer:**
    - Heart Rate: ResNet-18, MAE < 2.3 bpm
    - Respiration: BiLSTM, 97% accuracy
    - Sleep Stages: MLP, 94% accuracy
    - Fall Detection: 3D-CNN, 95% precision, 98% recall

3. Anomaly recognition layer: Abnormal pattern recognition
    - Medical knowledge graph
    - Bayesian inference
    - Dynamic adaptive thresholds

Model Training and Optimization
- Training dataset: 10,000+ hours of monitoring data, covering different age groups and health conditions

- Model compression: knowledge distillation + quantization, reducing model size by 78%

- Computational optimization: Sparse inference, reducing the amount of computation by 50%.

2.2.4 Edge Computing Technology
The system adopts a distributed edge computing architecture for data localization processing:

Hardware:

- CPU: ARM Cortex-A76 (2x2.2GHz) + A53 (4x1.8GHz)
- RAM: 4GB LPDDR4X
- Storage: 64GB eMMC 5.1
- Power: <15W

Software:

- OS: Custom Linux Kernel 5.10 LTS
- Middleware: EdgeX Foundry
- AI Inference: TensorFlow + ARM NN
- Security: ARM TrustZone

Data Flow:

Sensor Data Acquisition → Local Preprocessing → Feature Extraction → Model Inference → Result Analysis → Local Storage/Optional Cloud Synchronization

Security Mechanism:
- Data encryption: AES-256-GCM algorithm

- Secure boot: Ensure firmware integrity

- Identity authentication: Based on X.509 certificate

- Secure communication: TLS 1.3 protocol

Advantages of edge computing:

Through localized data processing, it not only solves the problems of network latency and bandwidth consumption in the traditional cloud computing mode, but also significantly improves the level of data security and privacy protection, and the system response time is shortened by 85% compared with cloud processing.

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3. Functions and Application Scenarios

3.1 Core Features

Functional modules	Technical implementation	Performance metrics	Economic benefits (estimated).
Resting heart rate monitoring	Millimeter-wave radar + rPPG fusion	Accuracy: ±1bpm Distance: 6-8m Refresh Rate: 1Hz	Reduce the cost of manual monitoring by 35% and detect cardiovascular risk in advance
Respiration rate monitoring	Millimeter-wave radar multi-point detection	Accuracy: ±1 time/min Distance: 6-8 meters Refresh rate: 0.5Hz	Early warning of respiratory system abnormalities reduces the number of night inspections by 40%
Gait analysis	Millimeter-wave radar point cloud tracking	Parameters: cadence, symmetry, stability can detect 10 abnormal gaits	Early warning of fall risk saves 8,000 yuan in medical expenses for every 1 fall reduction
Fall detection	Millimeter-wave radar + 3D-CNN	Accuracy: 96% Response Time: < 10 seconds False Alarm Rate: <2%.	63% reduction in emergency rescue time and 42% reduction in critical injury rate
Sleep analysis	Millimeter wave kinematic detection + respiratory variability	Sleep stage: 4 stages sleep score: 0-100 abnormal detection: apnea, frequent body movements	Sleep quality is improved by 25% and the risk of chronic diseases is reduced
Health alarms	Multi-indicator fusion analysis	Alert level: Level 3 Response time: <5 seconds, remote	The efficiency of medical staff has increased by 38%, and

		notification is supported	the handling time of emergency incidents has been reduced by 45%.

3.2 Application Scenarios

3.2.1 Home Elderly Care

Implementation plan:

- Device Deployment: Key areas like bedroom, living room, and bathroom
- Monitoring: Daily vitals, activity patterns, abnormal behaviors
- Alerts: App push to family, integration with community services
- Data Usage: Trend reports, intervention recommendations

Pilot Results (500 Households):

- Emergency Alert Success Rate: 98%
- Response Time Reduced: From 28 min to 9 min
- User Satisfaction: 4.8/5
- Estimated Benefits: CNY 12,000 annual savings per household; 40% reduction in home care costs

Case Study: In Fujian Province, deployment in 100 elderly households led to a 35% increase in rescue success rate, a 2.5-year average extension in independent living, and a 52% rise in caregiver peace-of-mind.

3.2.2 Hospital Ward Scene

Implementation plan:

- Deployment: Bedside monitoring units, centralized nurse station display
- Monitoring: Vitals, posture changes, bed-exit alerts
- Alerts: Real-time nurse station reminders, mobile push
- Data Usage: EMR integration, trend analytics

Pilot Results (Tier-1 Hospital):

- Nursing Efficiency Increase: 38%
- Patient Safety Events Reduced: 42%
- Nurse Satisfaction Up: 35%

- Estimated Benefits: 28% lower per-bed care cost; CNY 1.5M annual savings (100 beds)nursing cost per bed, annual saving of about 1.5 million yuan in operating expenses (based on 100 beds).

ROI: Payback in 18 months; 5-year total cost of ownership (TCO) 32% lower than conventional monitoring; richer patient data provided.

3.2.3 Rehabilitation & Elderly Institutions

Implementation plan:

- Centralized Monitoring System covering living and activity areas
- Monitoring: All-day health data, mobility evaluation, sleep quality
- Alerts: Tiered warnings, emergency response
- Data Usage: Personalized care plans, rehab assessments

Pilot Results (100-Bed Facility):

- Care Quality Score Up: 32%
- Night Shift Staff Reduced: 25%
- Emergency Response Time Down: 63%
- Estimated Benefits: ~CNY 6,000/year per bed saved; 40% increase in operational efficiency

Market verification: According to the data of a number of elderly care institutions that have been deployed, the system saves an average of 580,000 yuan in labor costs for each institution, improves service quality by 32%, increases customer satisfaction by 28%, and significantly improves the market competitiveness and brand premium ability of institutions.

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4. Technology Comparison and Innovation

4.1 Industry Benchmarking Comparison

Key Metrics	This System	Competitor A (Wearables)	Competitor B (Single Radar)	Competitor C (Vision-based)
Monitor distances	6-8 meters	Contact	3-4 meters	5-6 meters
Number of monitoring indicators	5+	3-4	2-3	2-3

Penetrating ability	Strong (penetrable bedding)	not	middle	not
Privacy Protection	high	high	high	low
Multi-target monitoring	Support (up to 4 people)	Single	Single	Support (in view)
Night/low light performance	Not affected	Not affected	Not affected	Reduced performance
Maintenance costs	Low (Charge-Free)	High (requires regular charging)	low	middle
Deployment complexity	middle	low	middle	high
Clinically validated accuracy	95-97%	90-95%	85-90%	80-85%
Payback period	18 months	36 months	24 months	30 months

4.2 Key Innovations

- **Multimodal Sensor Fusion Algorithm**
  Innovation: Kalman filter-based fusion of heterogeneous sensor data
  Advantage: Improves accuracy by 20% over single-sensor systems; adaptable to complex environments
  Implementation: Real-time signal quality assessment and dynamic weighting for optimal estimation

- **Micro-motion Detection Technology**
  Innovation: Sub-millimeter motion detection algorithm
  Advantage: Accurately detects micro-physiological signals (e.g., heartbeats, chest movement)
  Implementation: Phase interference enhancement, Doppler effect precision measurement, signal accumulation

- **Adaptive AI Inference Framework**
  Innovation: Dynamic model selection at the edge
  Advantage: Adjusts model complexity based on context, power, and user state
  Implementation: Multi-precision model cascade with task-priority scheduling and resource-aware inference

- **Health Risk Prediction Model**
  Innovation: Personalized health risk assessment from long-term monitoring
  Advantage: 23% more accurate than traditional methods; detects early risks 12–24 hours in advance

Implementation: RNN-based time-series modeling, personalized baseline adaptation, multi-factor scoring

Solve the pain points of the industry: shift from reactive response to active prevention, and greatly improve the effectiveness of intervention

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5. Clinical Validation

This system has completed 1,000 times of clinical verification in a cardiovascular hospital affiliated to a 985 university, compared with standard medical equipment (gold standard):

Measurement metrics	Sample size	Accuracy	standard deviation	Gold Standard Reference
Heart rate monitoring	12,46 times	98%	±2.1bpm	12-lead ECG
Respiration rate monitoring	10,23 times	98%	±0.8 times/min	Respiratory gas analyzer
Fall detection	8,54 times	95%	-	Video annotation
Sleep staging	7,85 hours	91%	-	Video annotation
In/out of bed detection	15,32 times	98%	-	Pressure sensor + video verification

Study Design:

- Double-blind cross-validation
- Multiple environments (wards, homes, eldercare centers)
- Multiple demographics (ages 18–85, various health statuses)
- Long-term tracking (up to 6 months)

Clinical significance: The system shows significantly higher consistency with gold-standard equipment than the industry average, offering a reliable contactless solution, especially for long-term continuous monitoring. It also captures up to 28% more risk signals missed by conventional methods.

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6. Deployment and Implementation

6.1 System Deployment Process

Needs Assessment:

- **Scenario Analysis**: Space layout, monitoring requirements, user characteristics
- **Environment Evaluation**: Electromagnetic conditions, network status, installation feasibility
- **Deployment Plan**: Number of devices, installation locations, network configuration

Hardware Installation:

- **Device Mounting**: Wall/ceiling brackets (compatible with standard 86 boxes)
- **Power Connection**: AC 220V/110V, PoE supported
- **Network Configuration**: Wired Ethernet / Wi-Fi / 4G / 5G (optional)

System Debugging:

- **Self-Test**: Sensor calibration, communication checks
- **Coverage Validation**: Area scanning, blind spot detection
- **Parameter Tuning**: Optimized based on specific use cases

User Training:

- **Operation Training**: System usage, data review, alert handling
- **Maintenance Guide**: Routine care, troubleshooting
- **Emergency Protocols**: Response procedures for urgent events

Deployment Efficiency: With a standardized deployment process and professional team support, a 100-bed facility can be fully deployed within 14 days—40% faster than the industry average, minimizing disruption to operations.

6.2 Data Security and Compliance

The system supports tailored deployment plans to comply with international data security and privacy standards:

- **GDPR** (EU General Data Protection Regulation)
- **HIPAA** (U.S. Health Insurance Portability and Accountability Act)
- **China**: Cybersecurity Law, Data Security Law, and Personal Information Protection Law

Security Measures:

- **Local Data Processing**: No cloud upload of sensitive physiological data

- **Encrypted Transmission**: TLS 1.3 + mutual authentication
- **Encrypted Storage**: AES-256 with secure key management
- **Access Control**: Role-based permission management
- **Audit Logs**: Full activity tracking and traceability

Security Certification: Custom deployment configurations ensure full compliance with regional regulations and come with supporting certification documentation.

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7. Roadmap for future development

7.1 Technology Upgrade Plan

Timeline	Version	Key Technical Upgrades	Market Value
2025 Q3	V2.0	• Enhanced base-layer algorithms for 60GHz radar • Improved sleep stage detection • Emotion state recognition	Improved user experience; stronger market competitiveness
2025 Q4	V2.5	• Individual recognition in multi-person scenarios • Early cognitive decline monitoring • Remote therapy effect evaluation	Expanded use cases; increased product value; higher user retention
2026 Q2	V3.0	• New 6-core NPU edge platform • Multisource health data fusion • Predictive health risk AI model	3× processing power; 25% improved prediction accuracy; greater market share

7.2 Application Ecosystem Expansion (Medium-term Planning).

1. **Medical Device Certification**
   - FDA 510(k) Certification (USA)
   - NMPA Class II Medical Device Certification (China)
   - CE MDR Certification (EU).

2. **Solution Expansion**
   - Chronic Disease Management Solutions: Cardiovascular Diseases and Respiratory Diseases, with a market size of 80 billion yuan
   - Rehabilitation Training Assistance System: Motor function assessment, rehabilitation progress monitoring, compound annual growth rate is expected to reach 22%

- Mental Health Monitoring Program: Behavior pattern analysis, mood swing warning, fill the gap in the market

Ecosystem Integration

- **Hospital HIS/EMR Connectivity:** Improves purchasing incentives
- **Smart Home Platform Integration**: Expands consumer market
- **Community Elderly Services Platforms**: Enables B2G opportunities

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8. Conclusion

The Multi-sensor AI Smart Health Monitoring System integrates Millimeter-wave radar, optical sensing, and artificial intelligence to address pain points in traditional health monitoring. It achieves non-contact, all-weather, multi-dimensional health monitoring while safeguarding user privacy and ensuring high accuracy. It is designed to serve elderly individuals, patients, and personnel in specialized industries with comprehensive health protection.

Through rigorous clinical validation and real-world deployments, the system has demonstrated significant value in improving monitoring quality, reducing care costs, and enhancing safety. With ongoing technological upgrades and scenario expansion, this system is positioned to become foundational infrastructure for future smart healthcare and elderly care services.

Cooperation method

Partnership Opportunities

We sincerely invite the following institutions and individuals to explore the possibility of cooperation:

- **- Elderly care institutions:** improve service quality, reduce operating costs, and create differentiated competitive advantages
- **- Medical institutions:** Expand the scope of out-of-hospital services, improve the effectiveness of chronic disease management, and reduce the rate of readmissions
- **- Insurance companies:** reduce claims risk, provide value-added services, and develop innovative insurance products

- **- Local governments:** Enhance the capacity of community elderly care services and optimize the allocation of medical resources
- **- Scientific research institutions:** jointly carry out applied research and technological innovation in related fields

Next Steps

If you are interested in learning more or working together, we offer the following support:

- **- System demonstration:** Make an appointment for on-site or online system function demonstration
- **- Pilot projects:** Customize a small-scale pilot program for your organization
- **- Technical consultation:** Provide professional technical consultation for specific scenarios
- **- Investment Opportunities:** Learn about project investment and partnership opportunities

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