Research Review on Age-Friendly Interaction Design in Smart Home Environments: From Home Textile Interfaces to Mobile Feedback

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ABSTRACT With the in-depth promotion of the home-based elderly care model, the aging-adaptive design of human-computer interaction systems for smart homes has become an interdisciplinary frontier in engineering and design. However, embedded sensing technology for household textiles and aging-adaptive mobile interface design have long been advanced separately by different disciplinary communities, lacking an integrated perspective. Based on the collaborative design framework of "input interface + feedback interface", this paper systematically sorts out the sensing mechanisms and aging-adaptive advantages of three types of household textile interfaces, including bedding, sofas & seating, and wearable textiles. It analyzes the integration and anomaly recognition processing paths of multi-source data from textile terminals in smart home systems, summarizes the laws of aging-adaptive mobile feedback design for elderly users and family caregivers, and reviews the methodological evolution of aging-adaptive human-computer interaction research. The review shows that: bedding textile interfaces have formed relatively mature engineering implementation approaches in sleep monitoring and vital sign collection, but low-amplitude signal noise suppression and body motion artifact separation remain the core bottlenecks restricting their popularization; sofa and seating interfaces exhibit significant potential in standing posture recognition and fall warning, and the problem of multi-sensor crosstalk urgently needs to be solved with individualized calibration mechanisms; wearable textile interfaces present outstanding all-weather sensing advantages, while washing durability and flexible connection reliability constitute the main engineering obstacles to long-term deployment. At the mobile feedback layer, semantic presentation for elderly users and multi-dimensional trend analysis for caregivers should be defined in a differentiated and collaborative manner at the system architecture stage, instead of sharing a single data view. These findings reveal that the collaborative design framework of textile-terminal sensing and mobile-terminal feedback is the key path to promote home-based elderly care systems from functional realization to in-depth user adaptation, and provide a theoretical reference for subsequent systematic design research and engineering practice.

INDEX TERMS age-friendly design,home textile interface,smart home,mobile interaction,textile sensing

I. INTRODUCTION

GLOBAL aging is accelerating, with the proportion of people aged 60 and over in China exceeding 20%. As home-based care has been increasingly prioritized as a mainstream care model, smart homes have shifted from entertainment and efficiency tools to health monitoring and safety infrastructure. The quality of human-computer interaction between the elderly and these systems directly determines the feasibility and safety of home-based care. Research in engineering, computer science, and human-computer interaction has accumulated rich achievements and established a relatively comprehensive knowledge system [1-4].

Nevertheless, existing research is obviously fragmented. Researchers focusing on textile embedded sensing mostly emphasize material and engineering implementation, such as conductive fibers, piezoelectric materials, and textile structures, but rarely extend to user interface design after data reception. In contrast, studies on age-friendly mobile interface design concentrate on visual presentation, simplified operation, and accessible interaction, often taking sensing data as a given input while ignoring constraints from upstream textile data collection. Few studies discuss the two in a unified framework, resulting in a lack of systematic design support for age-friendly smart home interaction from sensing to feedback [5].

This paper adopts an integrated perspective of "implicit input interface + explicit feedback interface". Home textile interfaces are positioned as continuous sensing terminals requiring no active participation of the elderly, while mobile interfaces serve as explicit information presentation and behavior guidance terminals, both serving the elderly users and their caregivers. Following this framework, the review covers: textile sensing, data processing, age-friendly mobile feedback design, and methodological evolution and future prospects.

II. HOME TEXTILE INTERFACES AS IMPLICIT INPUT TERMINALS

The core advantage of home textile interfaces over traditional active sensors lies in embedding sensing functions into daily textiles used by the elderly, eliminating the need for active wearing or operation, thus avoiding compliance problems caused by cognitive decline, operational difficulties, or resistance [6-8]. Classified by usage scenarios, they include three categories: bedding, sofa-seating, and wearable textile interfaces, each with typical tasks, engineering methods, and age-friendly characteristics.

A. BEDDING TEXTILE INTERFACES

Sleep is a high-density information source for the health of the elderly. Bedding textile interfaces continuously collect vital signs and body position information without intervention by utilizing long-term bed rest [9-11].

Current research covers multiple sensing principles: smart mattresses with flexible pressure sensor arrays infer heart rate, respiration rate, and turning frequency; non-invasive optical fiber interferometer mattresses capture micro body movements with high sensitivity and no direct skin contact with conductive devices; MAPU graphene/polyurethane composite mattresses combine self-recovery and high pressure resistance for comfort and accuracy [12-14]. Bed-exit detection and night fall prevention have been clinically verified, and some systems integrate RSSI indoor positioning to link sensing data with spatial context for early warning [15-16].

Compared with traditional polysomnography (PSG), bedding textile interfaces offer three advantages: no electrodes or wearable devices, reducing resistance to medical equipment; long-term data collection in natural home environments for real health status; and fully transparent operation with near-zero cognitive burden. These features make them one of the most feasible and compliant solutions for elderly sleep monitoring [17-19].

An in-depth examination of the engineering implementation pathways of bedding textile interfaces reveals an inherent logical correlation between the selection of sensing principles and aging-adaptive application scenarios. Flexible pressure sensor arrays have become the most mainstream implementation approach in current research due to their mature manufacturing processes and adjustable spatial resolution. However, the contradiction between array density and signal crosstalk limits the upper precision limit in full-body posture reconstruction for large-area mattresses. To address this bottleneck, the detection scheme based on fiber-optic Michelson interferometry senses body motion signals by capturing slight changes in optical path difference, and achieves high-sensitivity acquisition of heart rate and respiratory rate without relying on electrical contact. This scheme is completely immune to electromagnetic interference and presents a unique anti-interference advantage in smart home environments with numerous electronic devices. The graphene/polyurethane composite material (MAPU architecture) combines the high piezoresistive coefficient of conductive elastic materials with self-recovery deformation characteristics. Its elastic modulus is closer to that of human soft tissue, and its sensing drift under long-term lying pressure is significantly lower than that of rigid piezoresistive materials, thus providing unique adaptability in home-based elderly care scenarios requiring continuous deployment for months or even years.

All three types of sensing principles face a common signal decoupling challenge when applied to elderly users: respiratory movements, subtle heartbeat vibrations, and large-scale limb body motions are highly superimposed in the time domain. Moreover, elderly users tend to have a much higher probability of artifacts due to increased nighttime awakenings and irregular turning frequencies compared with healthy adults. The current mainstream solution is to introduce an adaptive filter bank at the signal preprocessing stage, design a multi-channel band-pass filtering link centered on the heart rate band (0.8–2.0 Hz) and respiratory band (0.1–0.5 Hz), and combine nonlinear denoising methods based on Empirical Mode Decomposition (EMD) or wavelet transform to recover the continuous estimation of vital signs within the reconstruction window after body motion events. Nevertheless, the hyperparameter setting of this strategy relies on signal statistical characteristics, and individual differences within the elderly population—including body weight distribution, sleep posture preference, and respiratory rhythm variability—lead to large fluctuations in recognition accuracy under unified parameters. Individualized modeling remains a key engineering threshold restricting the translation of bedding textile interfaces from laboratories to large-scale home deployment. The collaborative design framework bridges this technical gap by establishing a cross-layer parameters-passing channel, linking high-level mobile interaction directly with low-level signal processing algorithms. Specifically, the collaborative framework does not solve signal-to-noise ratio issues at the textile layer alone; instead, it uses the caregiver's mobile interface to harvest user baseline characteristics (e.g., body weight distribution, sleep posture preference, and basic respiratory rhythm). These user-contributed profiles act as prior hyperparameter constraints for the adaptive filter banks and Empirical Mode Decomposition (EMD) pipelines at the processing layer, drastically reducing the search space for signal decoupling. By leveraging the dual-end interface collaboration to feed customized constraints into the algorithmic end, the system effectively mitigates accuracy fluctuations caused by individual physiological heterogeneity.

From the perspective of application functions, the research scope of bedding textile interfaces has extended beyond simple sleep staging analysis to multi-functional integration. On the one hand, some studies have integrated a mattress sensor network with an indoor RSSI positioning system. By associating pressure signals on the bed with the spatial position information of the elderly in the bedroom, a sensing capability covering the complete behavior chain of "in-bed–out-of-bed–bedside activity" is constructed, enabling the system to trigger an early warning response immediately when getting out of bed rather than after a fall, thus advancing the intervention timing to the stage of high-risk actions. On the other hand, to meet the clinical demand of pressure ulcer prevention in hospitals, AI-driven smart pressure-relief mattresses have been verified by retrospective cohort analysis in middle-aged and elderly inpatients to be effective in preventing moderate-and high-risk pressure injuries by real-time monitoring of local continuous compression duration and actively triggering posture adjustment prompts. The migration of such technical pathways to home scenarios deserves further attention. Overall, the research on bedding textile interfaces is shifting from single physiological parameter collection to the integration of behavioral context awareness and active intervention support, a trend that imposes higher requirements for semantic structuring on the information content design of subsequent mobile terminal feedback.

B. SOFA AND SEATING TEXTILE INTERFACES

Prolonged sitting is a major cardiovascular risk for the elderly, and standing up from chairs is a high-risk scenario for falls. Sofa and seating textile interfaces use flexible pressure units or piezoelectric arrays embedded in cushions to detect pressure distribution, enabling posture recognition, sitting duration monitoring, and stand-up gesture capture [20-22]. Studies on age-friendly smart sofas based on skeleton key points show that combining pressure distribution and posture estimation algorithms accurately distinguishes normal, slow, and unstable standing, providing behavioral support for fall warnings. Passive piezoelectric arrays (no external power supply) are advantageous for long-term home deployment, and mesh textile structures improve compatibility with seating fabrics [23-24].

A key engineering challenge is signal crosstalk: dense sensor units cause overlapping pressure fields and reduced positioning accuracy. Spatial filtering and adaptive threshold calibration alleviate this issue, but individual calibration for users of different body shapes remains difficult in practice.

From the perspective of sensing principle selection, the core difference between sofa and seating textile interfaces and bedding interfaces lies in the time-domain characteristics of actions: bedding interfaces are mainly used for long-term static and continuous sensing, while sofa interfaces need to capture short-term and rapid transition movements from sitting to standing. The latter imposes higher requirements on the response speed and sampling frequency of sensing units. Piezoelectric sensor arrays have significant advantages under the power consumption constraint of long-term home deployment due to their inherent passive working mechanism—deformation directly generates electrical signals without continuous power supply. However, their output is essentially a differential quantity of deformation rate, with low sensitivity to slow body weight shifts. Therefore, they need to be mixed with capacitive or piezoresistive sensing units in sedentary recognition tasks to balance the two requirements of rapid motion capture and static load quantification. As an auxiliary sensing node, MEMS accelerometers are usually embedded in the armrest or leg structure of seats to assist in distinguishing the acceleration characteristics between unstable standing and normal standing of elderly users by capturing micro-vibration signals. The two types of behaviors are highly similar in the time-series curve of pressure distribution, and it is difficult to reliably distinguish them only by textile pressure signals. The fusion of acceleration signals substantially improves the classification accuracy.

To resolve the logical contradiction between image-based sensing and the "implicit interface" paradigm, recent intelligent sofa research utilizes skeletal key-point analysis exclusively as a laboratory benchmark rather than a home deployment strategy. The system synchronously inputs the seat cushion pressure distribution mode and the skeletal key-point coordinates from image pose estimation algorithms into a training-phase classification model to map the precise upper bound of behavioral features. To eliminate the severe privacy risks of optical cameras in private home environments and preserve the completely non-intrusive nature of the implicit framework, practical home deployments discard the image acquisition module entirely. Instead, researchers leverage this benchmark to optimize a pure textile-side multi-modal feature fusion scheme, which cross-references flexible pressure array patterns with structural MEMS accelerometer signals. This optimized approach improves the accuracy of distinguishing three states (normal standing, slow standing, and unbalanced leaning) by practically matching the performance of the image-fused benchmark without compromising user privacy. This transition provides a practical basis for enforcing absolute privacy boundaries at the intermediate data layer, ensuring that no optical data is generated or transmitted to subsequent mobile terminal interfaces.

In the age-friendly engineering improvement for elderly users, researchers of seating textile interfaces have gradually realized that the essence of the "individual calibration" problem is not only engineering parameter optimization but also the heterogeneity of body shape and variability of behavior patterns within the elderly group. Due to muscle atrophy, decreased bone mineral density, and changes in weight distribution, elderly users have a systematic deviation in the trajectory of their sitting pressure center from young and middle-aged groups. The standing movement characteristics of the same elderly user also differ significantly between good physical condition and fatigue state, leading to accuracy drift in the recognition model based on single calibration during long-term use. To address this problem, some studies have introduced an online learning mechanism based on individual historical data, which enables the model to continuously accumulate the user's individual behavior baseline during daily use and gradually improve the individual adaptation degree of recognition. The introduction of this mechanism means that the sensing ability of sofa and seating textile interfaces will be dynamically enhanced with the extension of use time, which also has a direct impact on the presentation strategy of mobile terminal feedback: the early warning threshold of the system should be conservative in the initial deployment stage and dynamically adjusted with the gradual establishment of the individual baseline. The feedback interface needs to convey the operation logic of this "learning system" to users to avoid the trust crisis caused by frequent false alarms in the early stage.

In summary, the three types of home textile interfaces differ in tasks, technologies, and user experiences; their core characteristics are summarized in Table 1.

C. WEARABLE TEXTILE INTERFACES

Wearable textile interfaces include smart clothing, sensing belts, and socks, integrating sensing into daily clothing for continuous monitoring of falls, abnormal gait, chronic disease signs, and long-term activity patterns [25-27]. Technically, e-yarn twists conductive fibers and elastic base yarns to maintain textile mechanical properties; conductive knit structures realize large-range strain sensing without extra sensing elements; textile electrodes knitted on shirts collect ECG and EMG signals [28-30]. For elderly patients with dementia who cannot express pain, wearable textile systems for pain and emotion perception have expanded application boundaries.

Two engineering challenges dominate: washing durability (electrical stability of conductive fibers and elastic substrates after repeated laundering) and wiring reliability (connection between flexible wires and rigid modules). Overall, wearable textile interfaces provide irreplaceable full-day coverage for fall detection and home-based chronic disease management.

From a detailed material engineering perspective, the sensing performance and aging-adaptive applicability of wearable textile interfaces depend largely on the design strategy of conductive structures. Electronic yarn (e-yarn) is usually produced by composite twisting of metal-coated fibers, stainless steel filaments, or silver-coated nylon yarns with elastic base yarns. The metal-coated scheme provides stable conductivity, but the coating suffers from microcrack accumulation under repeated bending and stretching, leading to irreversible increase in resistance after 50–100 machine washes. The stainless steel filament scheme offers excellent conductive durability, but its high linear density reduces fabric softness; elderly users have lower tolerance to fabric roughness due to increased skin sensitivity, imposing additional constraints on comfort adaptation. Silver-coated nylon yarns provide a good compromise between conductivity and softness, making them the most widely used conductive substrate in wearable textile interface research. However, silver ion migration under sweat infiltration poses potential risks to long-term skin-contact safety, and relevant toxicological evaluation has not been systematically conducted in elderly user studies. To circumvent this oversight and guarantee skin-contact safety for the immunocompromised elderly, recent material engineering practices introduce a biocompatible, ultra-thin polymer protective layer (such as Parylene-C vapor deposition or hydrophobic silicone microemulsion encapsulation) onto the yarn surface. This core-shell micro-structure acts as a physical barrier that prevents sweat from leaching silver ions, thereby neutralizing cytotoxicity risks. Concurrently, this flexible elastomeric coating seals the conductive pathways, dampening the accumulation of microcracks during stretching and washing cycles, which simultaneously extends the electrical durability and practical lifespan of the health monitoring garment.

Conductive knitted structures realize large-range strain sensing by utilizing the nonlinear variation of coil contact resistance under strain. Their advantage lies in that no additional discrete sensing elements are needed, since the sensing function is borne by the fabric structure itself, which fundamentally eliminates the risk of interface failure between rigid sensing elements and flexible substrates. Nevertheless, the strain response curve of coil contact resistance is often near the signal-to-noise boundary in low-amplitude body motion scenarios of elderly users (e.g., respiratory fluctuations, gait micro-vibrations), requiring signal conditioning circuits with high gain accuracy and common-mode rejection ability, which places non-trivial circuit design requirements on the miniature acquisition modules integrated on the textile side. Fabric-electrode ECG acquisition schemes have important clinical value in elderly chronic disease management. However, thickened stratum corneum and reduced sweat gland function in elderly users lead to significantly higher fabric-skin contact impedance than in young people, resulting in more severe attenuation of ECG signal amplitude. Signal quality is more dependent on wearing tightness, which is difficult to maintain consistently by elderly users during self-dressing, thus reducing the proportion of valid signal segments within the acquisition window and further increasing the burden of signal quality assessment and compensation at the algorithm end. To address the special clinical needs of elderly patients with dementia in pain and emotional expression, some studies have developed wearable textile-based pain perception and emotional state recognition systems. By integrating multi-dimensional physiological signals such as skin conductance, body surface temperature, and body motion acceleration, multimodal fusion classification algorithms are used to infer the patient's current discomfort level, and the results are

TABLE 1. Comparison of Sensing Principles and Age-Friendly Characteristics of Three Home Textile Interfaces

Textile Interface Type	Typical Sensing Tasks	Main Sensing Principles	Core Age-Friendly Advantages	Main Engineering Challenges
Bedding	Sleep monitoring, body position detection, vital signs collection, bed-exit warning	Flexible pressure array, optical fiber interference, conductive elastic materials	Implicit participation, high compliance, long-term deployment	Motion artifact separation, low-amplitude noise suppression
Sofa & Seating	Posture recognition, sitting detection, stand-up capture, fall warning	Piezoelectric array, MEMS accelerometer, flexible piezoresistive material	Embedded in daily scenes, no extra operation	Signal crosstalk, individual calibration
Wearable	Fall detection, gait analysis, chronic disease monitoring, activity recognition	E-yarn, conductive knit structure, textile electrode, sensing sock	Continuous wearable, full-day coverage	Washing durability, wiring reliability

transmitted to the caregiver-side mobile interface in the form of structured labels. The significance of this research direction is that it extends the sensing object of wearable textiles from measurable physical quantities (acceleration, resistance, pressure) to objective proxy indicators of subjective experience, enabling textile interfaces to perform information collection even for elderly groups with severely impaired cognitive ability, making up for the fundamental defect that traditional active interactive systems completely fail in dementia care scenarios. This expansion also imposes new requirements on the content organization of mobile terminal feedback interfaces: the system no longer outputs deterministic event labels but probabilistic evaluations with confidence intervals. The feedback interface should properly convey this uncertainty to caregivers while maintaining information simplicity, so as to avoid erroneous responses caused by overconfident interface wording.

As the primary engineering obstacle to the long-term deployment of wearable textile interfaces, washing durability presents a fundamental contradiction: textile sensing performance relies on the integrity of conductive paths, while mechanical shear force, thermal effect, and chemical action of detergents during washing together constitute periodic destructive loads on conductive structures. Current research strategies are divided into two categories: at the material level, conductive polymer coatings (e.g., polyaniline, PEDOT:PSS) are introduced to replace metal-based conductive structures, and the excellent elastic deformation recovery ability of organic conductors is used to improve washing fastness; at the structural level, the fabric structure is optimized to embed conductive yarns in the middle layer instead of laying them on the surface, reducing direct mechanical friction during washing. The reliability of connections between flexible wires and rigid acquisition modules is usually improved via magnetically adsorbed detachable connectors, allowing elderly users to easily separate electronic modules before washing without professional operation. However, this maintenance requirement introduces a secondary cognitive hurdle, as relying on users with cognitive decline to consistently remove modules before laundering directly challenges the "near-zero cognitive burden" premise of implicit sensing. To bridge this gap, future deployment must rely on either fully sealed, laundry-safe encapsulation materials or require that device maintenance loops be assigned exclusively to the caregiver interface via system-driven maintenance alerts, shifting the operational compliance burden away from the elderly user entirely. This design also reduces the requirement for fine motor ability of elderly users, complying with the basic design principles of aging-adaptive engineering (see Figure 1).

III. INTERMEDIATE LINK FROM SENSING TO FEEDBACK: DATA PROCESSING IN SMART HOME SYSTEMS

Before being transmitted to mobile feedback interfaces, data from textile interfaces undergo multi-source fusion, behavior recognition, anomaly detection, and early warning generation. The quality of this intermediate layer determines the granularity, timeliness, and semantic level of mobile information, constraining feedback design [31-33].

To systematically connect upstream material science with downstream user interface design, the intermediate data processing layer must execute a highly structured, multi-stage Data-to-Semantic Pipeline. This engineering pipeline sequentially transforms sub-verbal, physical-layer electrical outputs into explicit, high-level behavioral labels through the following operational steps:

Step 1: Signal-Level Preprocessing & Filtering: Raw analog electrical signals (e.g., continuous micro-voltage changes from textile piezoresistive sensors or frequency deviations from optical fiber interferometers) are localized, amplified, and passed through adaptive high-gain filter banks to separate core vital signs from large-scale motion artifacts.

Step 2: Feature-Level Multi-Source Fusion & Spatial Alignment: Cleaned heterogeneous data streams— comprising textile pressure grid matrices, localized MEMS acceleration vectors, and ambient environmental parameters— are windowed and synchronized via deterministic time-alignment matrix computations. This forms a high-dimensional, multi-modal feature vector representing the user's instantaneous physical behavior space [34-35].

Step 3: Pattern Classification & Behavior Label Mapping: These multi-dimensional feature vectors are injected into decision-level classification models (such as Random Forest or deep Transformer networks). The model resolves the sequential waveforms and outputs discrete, human-readable semantic behavior labels (e.g., sleeping, sedentary, unstable standing, gait anomaly).

Step 4: Baseline Comparison & Anomaly Evaluation: The mapped labels are continuously cross-referenced against the resident's historical, individualized behavioral baseline. The system quantifies deviations to extract clinically significant events, such as a sharp spike in nighttime awakenings or an acute drop in sitting stability, assigning an event type and a statistical confidence score.

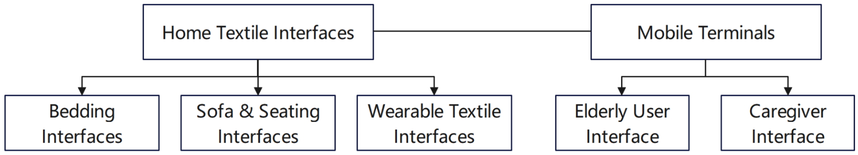

FIGURE 1. Technical Classification Tree of Age-Friendly Smart Home Interaction Systems

Step 5: Architectural Semantic Structuring for Mobile Output: Rather than exposing raw mathematical anomaly scores or raw time-series arrays, the processing architecture translates these findings into structured JSON payloads (containing Event_Type, Severity_Level, and Actionable_Recommendation). This standardized interface layer acts as the mandatory architectural bridge, feeding clean semantic summaries directly into the dual-end mobile feedback design.

Current research remains weak in this architectural coordination; most studies stop at verifying independent sensors and classification algorithms without formalizing this pipeline, resulting in a fragmented user experience that fails to match the requirements of age-friendly feedback design [36-37] (see Figure 2).

IV. AGE-FRIENDLY DESIGN OF MOBILE FEEDBACK TERMINALS

The mobile interface transforms sensing results into understandable information, actionable operations, and reliable experiences. It serves two user groups: the elderly and caregivers, with distinct cognitive characteristics, information needs, and usage scenarios, leading to different design requirements.

A. MOBILE INTERFACES FOR ELDERLY USERS

Visual, cognitive, and motor degradation form the basic constraints. Visual design emphasizes font size ($\geq$18pt), contrast ($\geq$4.5:1), color saturation, and icon recognizability. Operation relies on depth reduction and step simplification, as completion rates drop sharply for processes over three steps. Accessibility interaction (voice, gesture) compensates for motor decline but faces challenges of misrecognition and dialect adaptation. Multi-modal (visual, auditory, haptic) feedback reduces uncertainty and improves sustained usage [38]. Information design prioritizes status confirmation and simple suggestions over raw data. Semantic descriptions (e.g., "Your sleep quality was good tonight") are more suitable than sensor values, with clear operation paths.

B. MOBILE INTERFACES FOR CAREGIVERS

Caregivers need a balance between information density and emotional load. Health dashboards support quick overview and in-depth query: daily status at a glance and detailed history during anomalies. Early warning classification (emergency vs. routine) and secondary verification reduce alarm fatigue and cut invalid responses by about 40% [39].

Privacy boundaries matter: the elderly often resist full-time monitoring, especially in bathrooms and bedrooms. User-controlled privacy switches maintain autonomy and improve system acceptance [40-41].

C. DUAL-END COLLABORATIVE FEEDBACK MECHANISM

Differentiated presentation for the elderly and caregivers is under-explored. For the same event (e.g., frequent night urination), the elderly receive concise suggestions to avoid anxiety, while caregivers access time-series data, baselines, and risk scores for judgment [42]. To bridge the potential "trust gap" arising from such mismatched views—such as when an older adult receives a positive "good sleep" summary while the caregiver detects a "high-risk heart rate variability" anomaly—the dual-end system architecture must implement a logical reconciliation mechanism. When a high-risk physiological anomaly is detected, the system should dynamically downgrade the optimism of the elderly-end semantic feedback (e.g., modifying it to "You rested well, but please follow your caregiver's guidance for a routine check") to prevent a domestic trust crisis and ensure behavioral compliance without inducing active anxiety. Key dimensions are compared in Table 2.

TABLE 2. Comparison of Design Elements for Dual-End Collaborative Feedback

Design Dimension	Interface for the Elderly	Interface for Caregivers
Information Content	Semantic status, instant suggestions	Time-series data, trends, risk rating
Presentation Level	Conclusion (e.g., good sleep)	Raw data (heart rate, movement)
Notification Strategy	Low-frequency, active, positive	Graded, priority, anomaly-first
Privacy Control	User-defined sharing	Authorized data only
Complexity	Minimal ($\leq$3 steps)	In-depth query & filtering
Feedback Modality	Visual + auditory + haptic	Visual mainly with push alerts

Technical premise: layered background processing — raw data for caregivers, semantic summaries for the elderly, and graded warnings. Commercial products often use a single view and fail to realize differentiated design values.

V. USER RESEARCH METHODS AND FUTURE OUTLOOK

Age-friendly interaction research has evolved from qualitative to multi-method integration. Early work used small-scale interviews and observations to explore expectations, barriers, and privacy concerns, yielding frameworks and principles but limited generalizability.

With digital tools, text mining of reviews and social media complements small-sample limitations. Quantitative mod-

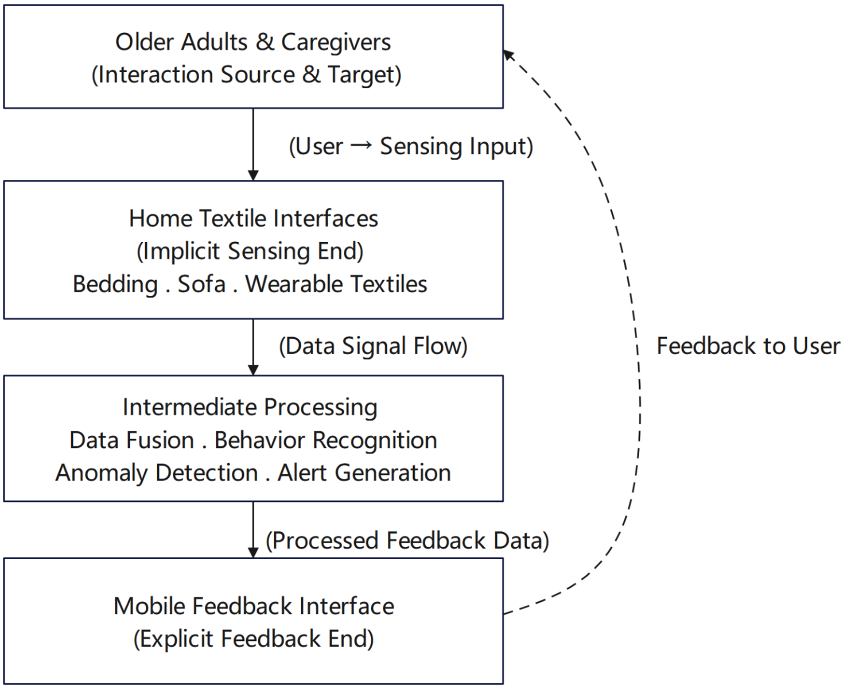

FIGURE 2. Collaborative Closed-Loop Framework of Age-Friendly Smart Home Interaction Systems

eling (TAM, SEM) verifies acceptance factors (usefulness, ease of use, social norms, trust), but metric adaptation for the elderly requires caution.

Objective data enhances rigor: eye-tracking reveals layout and cognitive load; physiological signals (EDA, HRV) measure emotional arousal; long-term logs evaluate sustained usage, compensating for short-term usability test biases [43-44]. The empirical viability of applying these multimodal objective methods within an integrated textile-mobile architecture has been demonstrated in recent pilot studies. For instance, researchers have successfully paired textile pressure-patch data streams with synchronized user eye-tracking matrixes to evaluate visual attention shifts during real-time alert triggers. Similarly, user interface studies have begun employing multi-sensor textile patches (e.g., PANI e-skin systems) alongside mobile feedback logging to cross-verify the cognitive load profiles of elderly users against their physiological stress indicators during interface interactions, establishing a solid empirical precedent for this methodological shift.

Future research should strengthen collaborative design between textile sensing and mobile feedback, establish a complete system evaluation paradigm, and develop personalized dual-end adaptation strategies for cognitively heterogeneous elderly groups, integrating engineering technology and user experience (see Figure 3).

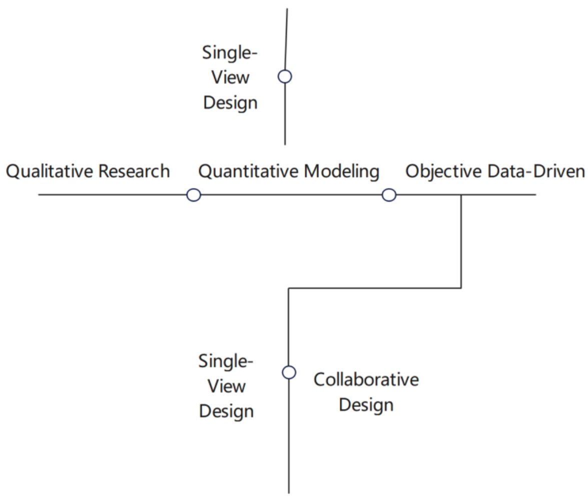

FIGURE 3. Evolution of Age-Friendly Interactive Systems and Research Method Pathways

VI. CONCLUSION

This paper takes the collaborative design of "recessive input interface + explicit feedback interface" as a unified framework, and systematically reviews the engineering implementation of home textile sensing interfaces, the multi-source data processing paths in smart homes, the age-friendly design rules of mobile terminal feedback, as well as the evolution of research methods in related fields. Based on the comprehensive review, conclusions are drawn from three dimensions: technical implementation, system integration, and design methodology. At the level of technical implementation, the three types of home textile interfaces have verified the feasibility in their core application scenarios, but there are still obvious engineering shortcomings before large-scale home application. The core bottleneck of bedding interfaces lies in the precise decoupling of low-amplitude vital signs and body motion artifacts. Existing filtering and decomposition methods lack generalization ability in the elderly group, and the engineering application of individualized modeling needs to be promoted urgently. Sofa and seating interfaces are mainly affected by signal crosstalk and physical heterogeneity. Online learning and dynamic threshold adjustment are potential solutions, but their long-term stability needs to be verified by longitudinal studies in real home environments. For wearable interfaces, mature schemes have not been formed in washing durability and flexible connection reliability. Conductive polymer coatings and magnetic connectors are promising, but long-term empirical data for the elderly are insufficient. At the level of system integration, the data processing layer between textile sensing and mobile feedback has been seriously neglected in existing research. Most studies only focus on the verification of sensors and algorithms, without coordinating the output specifications of the processing layer with interface design. This review shows that the semantic level of the processing layer output directly determines the design space of mobile feedback. Sensing engineering, data processing, and interface design must be decided collaboratively at the system architecture stage, which is the key to solving functional fragmentation and inconsistent user experience.

At the level of design methodology, mobile interfaces for the elderly and caregivers are fundamentally different. The common practice of sharing a single data view in commercial products ignores the cognitive adaptation needs of the elderly. Dual-terminal collaboration requires hierarchical data processing at the system level: providing semantic summaries for the elderly and complete raw data for caregivers. Meanwhile, age-friendly research is transforming from subjective measurement to objective behavioral data-driven, but the reliability and validity of related methods in the elderly with cognitive heterogeneity still need systematic verification.

In summary, to promote the practical application of age-friendly smart home systems, it is necessary to strengthen the robustness of textile sensing under the heterogeneity of the elderly, deepen the collaborative design between the sensing terminal and the feedback terminal, and establish a longitudinal research paradigm based on long-term home behavior data. This will provide a solid theoretical and practical foundation for the engineering implementation and experience optimization of intelligent home-based elderly care systems.

AUTHOR CONTRIBUTIONS

Conceptualization-Lisheng Chen and Xin Zhang; methodology-Lisheng Chen and Xin Zhang; investigation -Lisheng Chen and Xin Zhang; writing-original draft preparation-Lisheng Chen and Xin Zhang. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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