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Review Article

A Comprehensive Review on Gesture-Controlled Smart Home Systems for Elderly and Disabled Individuals

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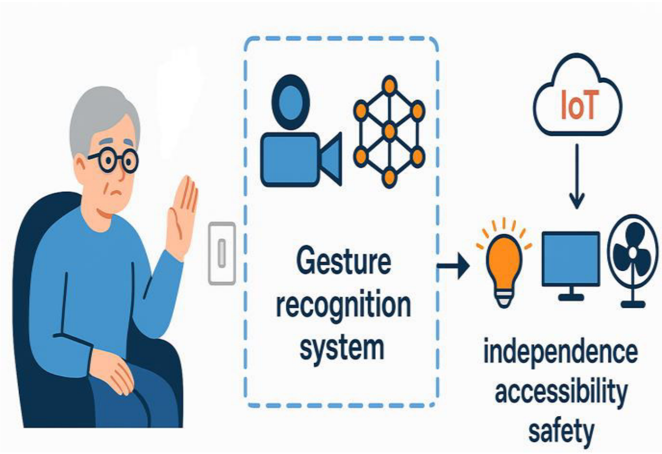
Abstract: The increasing global population of elderly and physically disabled individuals has highlighted the urgent need for accessible and inclusive smart home technologies. Gesture-controlled systems offer a promising, non-verbal interface for home automation, enabling greater independence and reducing reliance on caregivers. This survey presents a comprehensive review of gesture-based smart home systems specifically designed for elderly and physically impaired users, focusing on technological advancements, usability, and system-level challenges. The study systematically examines literature from the past decade, analyzing key dimensions including gesture recognition methods, sensor modalities, system integration, user accessibility and security. Deep learning techniques such as convolutional neural networks (CNNs) and sensor fusion approaches have led to improved gesture recognition accuracy. However, issues such as environmental sensitivity, limited real-world validation, and lack of standardized benchmarks persist. A chronological review traces the evolution of these systems—from early infrared and wearable technologies to current AI-enhanced, IoT-integrated, multimodal platforms. Despite technical progress, challenges remain in terms of user fatigue, gesture variability, hardware intrusiveness, and inconsistent evaluation methodologies. Moreover, critical aspects such as security, scalability, and personalized interaction are often underexplored. This review identifies major research gaps and proposes future directions including the development of adaptive gesture sets, robust multimodal frameworks, ergonomic sensor designs, and privacy-aware authentication mechanisms. Emphasis is placed on user-centered design and longitudinal field testing to enhance practical applicability. By consolidating current knowledge and highlighting future opportunities, this review aims to guide researchers and developers toward creating inclusive, reliable, and scalable gesture-controlled smart home systems that better support the needs of elderly and disabled individuals.

Keywords: Gesture recognition, Home automation, Elderly and disabled, Deep learning, IoT, Security, Chronological review, Research gap

Graphical Abstract- The graphical abstract illustrates the concept of a gesture-controlled smart home system designed for elderly and disabled individuals. On the left, an elderly person uses simple hand gestures instead of relying on physical switches. These gestures are captured and analyzed through a gesture recognition system that integrates camera-based sensing with AI algorithms. The recognized commands are transmitted via IoT frameworks to control home appliances such as lights, fans, and digital devices. The outcome highlights improved independence, accessibility, and safety, emphasizing how gesture-controlled systems reduce reliance on caregivers and enhance the quality of life for mobility-impaired users.



1. Introduction

Research on gesture-based home automation systems for feeble individuals has emerged as a critical area of inquiry due to the increasing need for accessible and inclusive technologies that enhance independence for people with physical disabilities and the elderly [1,2]. The evolution of home automation has progressed from traditional voice and app-based controls to more intuitive gesture recognition methods, leveraging advances in computer vision, machine learning, and IoT integration [3,4]. This shift addresses practical challenges faced by users with limited mobility, offering non-verbal, contactless interfaces that improve quality of life and reduce caregiver dependence [5,6]. With over 65 million people worldwide experiencing mobility impairments [7], the social and practical significance of developing effective gesture-based systems is underscored by demographic trends and the growing elderly population [8,9].

Despite numerous advancements, significant challenges remain in designing gesture-based home automation systems that are reliable, user-friendly, and adaptable to diverse disabilities [10,11]. Existing solutions often suffer from limitations such as environmental sensitivity, high costs, or inadequate customization for specific user needs [12,13]. Moreover, controversies persist regarding the optimal sensing modalities—ranging from vision-based recognition to wearable sensors and inertial measurement units—and their trade-offs in accuracy, latency, and usability [14,15]. Failure to address these gaps risks perpetuating accessibility barriers and undermining the potential benefits of smart home technologies for feeble populations.

The specific objectives of the review are as follows:

- To critically analyze and synthesize various research efforts in gesture-based home automation systems for physically impaired users.
- To make a comparative analysis of different studies carried out on gesture-controlled smart home systems.
- To conduct a chronological review of technological evolution in the field.
- To highlight existing limitations in research and suggest prospective trajectories for advancement and implementation.

The subsequent sections of the paper are structured as follows. Section 2 provides a critical synthesis of the literature across various system aspects. Section 3 conducts chronological review of literature. Section 4 discusses different performance metrics. Section 5 discusses key results of the survey. Section 6 identifies research gaps and proposes future research directions. Section 7 concludes the research work.

2. Critical Analysis and Synthesis

This section provides a comprehensive critical evaluation of existing gesture-based home automation systems developed for elderly and physically disabled individuals. Drawing from the literature, seven core dimensions are analyzed to understand the capabilities, limitations, and current trends shaping this domain.

2.1 Gesture Recognition Techniques

Strengths:
Recent advancements in deep learning, particularly convolutional neural networks (CNNs), YOLOv8, and self-supervised learning frameworks, have significantly improved gesture recognition accuracy—often exceeding 95% in controlled settings. Systems utilizing multimodal data sources, such as inertial measurement units (IMUs) and computer vision, exhibit enhanced robustness and adaptability to varied gestures.

Limitations:
However, many recognition systems depend on stable lighting conditions and predefined backgrounds, limiting reliability in real-world environments [16]. Vision-based approaches frequently struggle with occlusions, gesture ambiguity, and inter-user variability [17]. Furthermore, the absence of uniform datasets and reliable evaluation protocols hinders objective comparisons among various studies.

2.2 Usability and Accessibility for Physically Impaired Users

Strengths:
Several studies prioritize user-centric design, enabling intuitive and non-verbal communication through natural hand gestures, which improves independence and quality of life [18]. Wearable devices and glove-based systems offer portability and ease of use for users with limited mobility [19, 20]. Systems incorporating multimodal inputs (gesture plus voice) provide flexible interaction modes.

Limitations:
Usability evaluations are often limited to small or non-diverse user groups, reducing generalizability [21]. Fatigue and variability in gesture performance among elderly or disabled users are insufficiently addressed, potentially impacting long-term adoption [22]. Some wearable solutions may be intrusive or uncomfortable for continuous use [23].

2.3 Sensor Modalities and Hardware Integration

Strengths:
The combination of vision-based sensors (e.g., cameras, Kinect, MediaPipe) with inertial measurement units (IMUs) and electromyography (EMG) sensors enhances gesture detection accuracy and accommodates users with different impairments [24,25]. IoT integration using protocols like MQTT and ESP8266 facilitates seamless appliance control and remote monitoring.

Limitations:
Vision-based systems are sensitive to lighting and require precise camera placement, which may not be feasible in all home environments. Wearable sensors can increase system complexity and cost, and may require frequent calibration [26]. Hardware heterogeneity complicates interoperability and scalability [27].

2.4 Security and Authentication Mechanisms

Strengths:

Some systems incorporate user authentication through face recognition or multimodal verification to enhance security and prevent unauthorized access. Alerting features for caregiver notification improve safety for vulnerable users.

Limitations:

Security considerations are often secondary and underexplored, with limited discussion on data privacy, secure communication, and protection against spoofing [28]. The integration of authentication mechanisms can increase system complexity and latency.

2.5 Environmental and User-Specific Challenges

Strengths:

Research acknowledges challenges such as lighting variability, gesture variability, and user fatigue, with some proposing adaptive algorithms and sensor fusion to mitigate these issues. Systems designed for specific impairments (e.g., Parkinson's tremor detection) demonstrate tailored solutions.

Limitations:

Many studies lack comprehensive real-world testing under diverse environmental conditions and with heterogeneous user populations. Fatigue and cognitive load effects on gesture performance remain insufficiently addressed. The adaptability of systems to individual user needs and preferences is limited.

2.6 Methodological Rigor and Evaluation

Strengths:

Several papers employ rigorous machine learning training with large datasets and report quantitative metrics such as accuracy, precision, and recall. Some include online testing with users not involved in training, enhancing validity.

Limitations:

There is inconsistency in evaluation metrics and datasets used, impeding cross-study comparisons. User studies often have small sample sizes and lack longitudinal assessment. Few studies report on system latency, power consumption, or cost-effectiveness comprehensively [29].

2.7 System Scalability and Practical Deployment

Strengths:

IoT-enabled frameworks and modular architectures support scalability and integration with diverse home appliances. Customizable gesture sets and mobile app interfaces enhance user adaptability [30].

Limitations:

Practical deployment challenges include hardware costs, installation complexity, and maintenance requirements. Many prototypes remain at proof-of-concept stage without extensive field trials. The need for caregiver or technician support for system configuration persists [31].

Table 1. Comparative Analysis of different studies

Study	Recognition Accuracy	User Accessibility	System Responsiveness
(Mwangi et al., 2024)	High accuracy with CNN-based gesture detection	Designed for physically disabled and visually impaired users	Real-time control with webcam and Arduino integration
(Besenk et al., 2024)	Precise hand detection using fine-tuned YOLO-V8	Ceiling-mounted camera enhances usability for disabled users	Responsive gesture-to-command conversion demonstrated
(Ding & Xiao-hu, 2024)	96% accuracy with Yolo-v5 and transfer learning	Tailored for elderly with mobility issues and tremor detection	Real-time gesture classification and appliance control
(Elsayed et al., 2024)	Improved accuracy via contrastive predictive coding framework	Enhances user experience for elderly and disabled	Real-time hand gesture recognition with deep learning
(SusilaSakthy et al., 2024)	Reliable real-time detection using CNN and hand tracking	Prioritizes independence for mobility-impaired users	Immediate appliance control with gesture commands
(Avadut & Udgata, 2022)	98.67% classification accuracy with CNN on IMU data	Wearable sensors for senior citizens and physically challenged	Real-time data segmentation and classification
(Rustam et al., 2023)	94% accuracy using PCA, LDA, and random forest classifier	Healthcare and industrial applications for disabled users	Real-time inertial sensor-based gesture detection
(Qin & Song, 2023)	High accuracy (93.62%) multimodal interaction	Incorporates five independent interaction modalities	Provides real time feed back to users

3. Chronological Review of Literature

Research on gesture-based home automation systems for physically frail and disabled individuals has evolved steadily over the past two decades. Early work focused on developing basic gesture recognition interfaces and wearable devices to facilitate interaction with home appliances for users with limited mobility. Over time, integration of machine learning, computer vision, and IoT technologies enhanced system accuracy, usability, and adaptability. Recent studies emphasize multimodal interaction, security, and personalized user experiences to improve independence and quality of life for elderly and disabled populations.

3.1 Foundational Gesture Interfaces for Accessibility (2000-2010)

Initial studies introduced wearable gesture devices and simple infrared-based systems aimed at enabling physically impaired users to control home appliances. Research explored natural and intuitive gesture sets, focusing on overcoming mobility limitations and improving independence through non-verbal interaction methods.

3.2 Vision-Based Recognition and Sensor Integration (2011-2014)

During this phase, innovations included the use of computer vision, stereo cameras, and sensors such as accelerometers and gyroscopes to capture hand gestures for home automation. Systems began incorporating smartphones and multimodal inputs, enhancing interaction flexibility and targeting elderly users with reduced dexterity.

3.3 Machine Learning and Multimodal Systems (2015-2017)

This period introduced the application of machine learning algorithms, including convolutional neural networks (CNNs), long short-term memory (LSTM) models, and random forests, to enhance gesture recognition accuracy and real-time responsiveness. Multimodal systems[32] combining speech, gestures, and physiological signals were developed to enhance robustness and cater to diverse impairments in home environments.

3.4 IoT Integration and Assistive Smart Home Environments (2018-2020)

Research attention shifted towards combining IoT infrastructure with gesture recognition to enable seamless control of multiple smart devices. Wearable technology, low-power sensor arrays, and augmented reality interfaces were introduced to improve user experience and accessibility for elderly and disabled individuals.

3.5 Advanced Deep Learning and Security-Enhanced Gesture Systems(2021-2024)

Recent works include deep learning models such as CNNs and self-supervised learning frameworks to boost recognition accuracy and adaptability across varied conditions. Security mechanisms, multimodal authentication, and combined health monitoring features are integrated to provide inclusive, safe, and autonomous smart home solutions tailored for feeble users.

4. Performance Metrics

The performance of gesture controlled home automation system is often evaluated based on several metrics, which are crucial for assessing their effectiveness and usability.

4.1 Accuracy

It is the ability of the system to correctly recognize and interpret gestures. Accuracy is typically expressed in percentage.

4.2 Response Time

The time taken by the system to process a gesture and execute the corresponding command. Low latency is essential for seamless interaction and avoid confusion.

4.3 User Experience

The overall satisfaction of users with the system, including ease of use and intuitiveness. Complex gestures reduce usability.

4.4 Reliability

The consistency of the system in performing tasks without errors or failures. System should be highly reliable.

4.5 Accessibility

The extent to which the system can be used by individuals with various disabilities. Accessibility decreases for individuals with severe motor impairments.

4.6 Energy Efficiency

The system’s ability to minimize energy consumption while maintaining performance.

5. Results and Discussion

This section synthesizes insights, trends, and key observations from the reviewed literature on gesture-controlled smart home systems for elderly and disabled users. It highlights patterns in recognition techniques, system performance, usability, and real-world applicability.

5.1 Trends in Gesture Recognition Techniques

Deep learning-based methods, particularly CNNs and YOLO models, dominate the field due to their high recognition accuracy (94–98.67%). Vision-based systems remain popular for non-intrusive interaction, whereas wearable IMU and EMG sensors are preferred for personalized, fatigue-resistant gesture detection. Multimodal systems combining vision and sensor inputs show the greatest promise in improving robustness and adaptability.

5.2 Usability and Accessibility

Studies consistently emphasize user-centered design for elderly and disabled populations. Systems integrating simple, intuitive gestures and multimodal interaction modes (gesture + voice) enhance accessibility and independence. Wearable devices provide mobility support but may face adoption barriers due to comfort issues, calibration needs, or intrusiveness. Real-time responsiveness is critical. Most systems successfully enable immediate appliance control, which is essential for practical deployment in daily living environments.

5.3 System Performance Insights

From comparative analysis and literature synthesis we found out the following.

- Accuracy is generally high across all systems, with CNN-based models on IMU data achieving peak values (98.67%).

- Response time is consistently low in most real-time implementations, enabling effective interaction for frail users.
- Reliability and scalability remain a challenge, especially for systems tested only in controlled environments.
- Environmental sensitivity (lighting, occlusion) and gesture variability continue to affect system robustness, emphasizing the need for adaptive algorithms and sensor fusion.

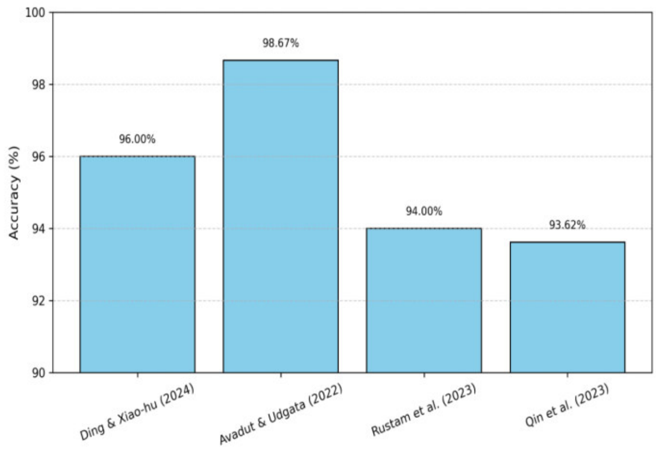


Figure 1. Recognition accuracy reported in surveyed research works

6. Gaps and Future Research Directions

Despite significant progress in gesture-based home automation systems, several critical research gaps remain that must be addressed to achieve inclusive, scalable, and real-world deployable solutions for feeble individuals. The following areas outline key limitations and propose future directions:

6.1 Standardization of Evaluation Metrics and Datasets

The lack of uniform datasets and reliable evaluation metrics obstructs impartial comparisons among various systems. Future work should focus on developing benchmark datasets and unified evaluation protocols specifically tailored for elderly and physically impaired users. Open access to datasets and reproducible evaluation results must be encouraged to foster collaborative advancement.

6.2 Robustness to Environmental Variability

Vision-based systems remain sensitive to variations in lighting, occlusions, and camera placement, limiting reliability in real-world conditions. Research should explore adaptive algorithms, sensor fusion (e.g., combining vision with IMU/EMG data), and robust hardware alternatives such as depth cameras to improve environmental adaptability.

6.3 User Fatigue and Gesture Variability

Current systems insufficiently account for fatigue, tremors, and inconsistencies in gesture execution common among elderly users. Longitudinal studies are needed to evaluate fatigue-related performance degradation. Future models should incorporate tremor detection and adapt to individual gesture variability through personalized calibration.

6.4 Security and Authentication Integration

Most systems lack comprehensive security features, with limited exploration of authentication mechanisms and data privacy safeguards. Design and integrate multimodal authentication (e.g., face recognition, gesture patterns, voice) with secure communication protocols. Evaluate impact on latency and usability and develop privacy-preserving frameworks.

6.5 Multimodal Interaction for Diverse Disabilities

There is limited exploration of combining gesture recognition with other modalities (voice, physiological signals) to accommodate a wider range of disabilities. Develop and evaluate multimodal interfaces integrating gestures, voice, EEG, and other biosignals.

6.6 Wearable Device Comfort and Usability

Sensor-based wearable systems may be intrusive, uncomfortable, or require frequent calibration, reducing user adoption. Research should prioritize ergonomic designs, lightweight materials, and self-calibrating sensors. User-centered design approaches must evaluate comfort, long-term usability, and potential non-wearable alternatives.

6.7 Real-World Deployment and Scalability

Most systems remain at the prototype stage with minimal field validation. Future research should include large-scale, longitudinal studies in real home environments. Emphasis should be placed on developing cost-effective, modular, and easy-to-install systems, along with caregiver-friendly configuration tools.

6.8 Adaptive and Personalized Gesture Sets

Many existing systems employ static gesture vocabularies, which may not align with individual user capabilities. Future research endeavors ought to prioritize the advancement of adaptive learning algorithms that tailor gesture sets in accordance with individual user inclinations, levels of fatigue, and overall physical condition, thereby facilitating the dynamic modification and personalization of gestures.

6.9 Latency and Real-Time Performance Optimization

Latency and response time are often underreported, affecting real-time usability. Research should aim to optimize recognition algorithms and hardware for low-latency performance while maintaining accuracy. Real-world benchmarking of responsiveness is essential to ensure system practicality.

7. Conclusion and Future Scope

This review has systematically examined the evolution, methodologies, and practical implications of gesture-based home automation systems tailored for feeble individuals, particularly the elderly and physically impaired. The synthesis of existing literature reveals a commendable trajectory of technological advancements — from early infrared and wearable devices to modern AI-powered, multimodal, and IoT-integrated systems. These innovations hold significant promise in enhancing accessibility, independence, and quality of life for users with mobility challenges.

Despite notable progress, the review highlights persistent limitations in real-world applicability, particularly concerning environmental sensitivity, gesture variability, and limited usability testing across diverse user populations. Key challenges include the lack of standardized evaluation frameworks, insufficient attention to user fatigue, security vulnerabilities, and the discomfort associated with wearable technologies. Furthermore, the disparity in datasets, sensing modalities, and performance benchmarks hampers cross-study comparability and broader adoption.

To address these gaps, future research must emphasize the development of adaptive, personalized, and scalable systems. This includes exploring robust sensor fusion techniques, real-time performance optimization, and user-centric design approaches that prioritize comfort, inclusivity, and ease of deployment. Integrating multimodal interactions - combining gesture, voice, physiological signals, and contextual awareness - can further expand system usability across a wider spectrum of disabilities.

In conclusion, while gesture-based home automation systems for feeble users show substantial potential, translating this innovation into practical, reliable, and widely adopted solutions requires continued interdisciplinary collaboration, rigorous field validation, and a stronger focus on user diversity and personalization. By addressing these critical research directions, future systems can better fulfill their promise of fostering truly inclusive smart home environments.

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Authors' Contributions - Author-1 was involved in initial draft of introduction and critical analysis and synthesis. Author-2 was involved in drafting of the chronological review of literature. Author-3 performed comparative analysis of various research works. Author-4 and 5 identified the research gaps and proposed future research directions. The final draft of the work was examined, revised, and approved by all writers.

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