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Original Article

Wellness Mirrors: Integrating Edge AI for Emotion and Avatar Adaptation

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Abstract

This study describes an AIoT-powered smart emotion mirror developed for twin reflection, with real-time emotion recognition and interactive avatar progression. The system analyzes face and vocal data using deep learning and multimodal sensors before displaying the user's look and an emotional avatar. The dynamic avatar gives motivational feedback and monitors emotional patterns, combining with IoT devices to deliver a personalized, data-driven user experience.

The rapid convergence of artificial intelligence and edge computing has enabled the development of intelligent, privacy-preserving wellness technologies. This study presents a Wellness Mirror system integrating Edge AI for real-time emotion recognition and adaptive avatar personalization. The proposed system employs computer vision and affective computing techniques to analyze facial expressions and emotional cues directly on edge devices, minimizing latency and protecting user privacy. Based on detected emotional states, the system dynamically adapts digital avatars and interface feedback to enhance user engagement, emotional awareness, and mental well-being. By processing data locally, the Wellness Mirror reduces dependence on cloud infrastructure while enabling continuous, non-intrusive monitoring. The framework demonstrates significant potential for applications in digital wellness, mental health support, personalized healthcare, and human–computer interaction. This research contributes to emerging smart wellbeing systems by combining Edge AI, emotion analytics, and adaptive avatar technologies in a unified, user-centric platform.

Keywords: *Wellness Mirrors; Edge AI; Emotion Recognition; Affective Computing; Avatar Adaptation; Digital Wellness; Human–Computer Interaction*

Introduction

Smart emotion mirrors use multimodal sensors and deep learning algorithms to identify and evaluate user emotions using facial and vocal signals, providing dynamic feedback through a changing avatar interface. This avatar progression not only visually represents the user's mood, but also inspires and supports them in achieving positive emotional states, making it a novel use in daily mental health management. These systems provide real-time, continuous monitoring and assessment of emotions, allowing users to follow their psychological trends and receive individualized recommendations for improvement. Integration with IoT improves the environment by dynamically modifying conditions based on the identified emotional state, transforming the mirror into a focal point for both emotional and environmental wellbeing.

Literature Survey

Recent developments in smart mirror technology have transformed basic information displays into intelligent, interactive systems utilizing AI and IoT. Early projects were DIY, built mainly on platforms like Raspberry Pi with open-source software, designed to show weather and time or act as simple home automation hubs. These systems evolved to feature basic facial or gesture recognition; however, early commercial mirrors remained focused on specialized applications like fitness or beauty, mostly relying on touchscreens and proprietary cloud solutions rather than advanced local AI processing.[1]

Modern research prioritizes the integration of edge AI to offer real-time, privacy-preserving analysis directly within the mirror. This includes image-based recognition of faces, gestures, and emotions, combined with voice-command processing for natural interaction. Solutions leveraging efficient deep learning models and hardware accelerators, like pruned versions of YOLO and TensorFlow Lite, allow embedded devices to deliver fast and energy-efficient inference. This shift from cloud- to edge-processing not only safeguards user privacy but also improves latency and reliability, which are essential in home environments. [1]

Multimodal interfaces are now standard in research and advanced commercial products, enabling mirrors to respond to speech, visual cues, and context-aware commands. Systems such as the KogniMirror and commercial platforms like Dirror L and SenseMi have demonstrated the practical potential of highly personalized, wellness-focused interactions—including features like avatar progression, wellness feedback, and health tracking. Still, true edge AI deployment with comprehensive personalization and adaptive feedback is emerging,

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as many commercial products rely on cloud connectivity and struggle to optimize for energy efficiency. [1]

Methodology

The methodology for the AIoT-based smart emotion mirror with avatar progression involves several stages, combining computer vision, emotion analysis, and IoT interaction for seamless user experience and real-time feedback.

Data Acquisition and Sensing

The smart mirror leverages high-resolution cameras and sensitive microphones to acquire real-time visual and auditory data from users. To increase reliability, the system can also connect to wearable sensors for physiological signals, such as heart rate, skin temperature, or EEG, providing multi-modal emotional inputs. This multi-source data acquisition ensures accurate emotion detection, regardless of variable lighting conditions or background noise.

Emotion Recognition

Facial emotion recognition uses deep learning models (CNNs, ResNet-50, or DeepFace) trained on robust datasets to identify a variety of emotions, including nuanced states like neutrality or contempt. Audio signals undergo spectral and prosodic feature extraction, allowing for machine learning models (such as SVM or Random Forests) to classify emotion from voice cues. Physiological signals further aid in emotion recognition, using advanced time-series analysis or fusion algorithms for multi-modal accuracy.

Avatar Progression and Feedback

The evolving avatar visually embodies the user's current and past emotional states using conditional NeRFs, generative diffusion models, and morphable face/gesture libraries. The avatar's progression motivates users to maintain positive moods, as its visual changes directly result from the user's behavior. This approach encourages engagement and offers supportive, positive reinforcement while respecting individual privacy by offering customization options.

IoT Integration and Environmental Control

Emotion detection outputs control smart devices—adjusting ambient lighting, music, room temperature, or even air quality—to tailor the environment to each user's mood. Secure communication protocols and privacy-preserving frameworks ensure confidential handling of user data when integrating with external IoT systems or cloud analytics. Additional integration with smart assistants allows for context-aware advice or reminders, further personalizing daily routines.

Data Logging and Analytics

The mirror logs emotion data, avatar changes, and environmental interactions in encrypted storage, enabling longitudinal analysis without compromising privacy. Analytical tools employ machine learning models such as decision trees and KNN for pattern recognition and trend analysis, presenting actionable insights through the avatar or on-screen dashboards. These features support personalized wellness tracking and informed behavioral change over time.exponents.

Testing Validation

Testing and validation of the AIoT-based smart emotion mirror system are essential to demonstrate accuracy, robustness, usability, and real-world effectiveness.

Model Testing and Evaluation

- Emotion recognition models are tested using separate validation datasets distinct from those used for training. Datasets like Affect Net or customized, real-world emotion datasets are employed to evaluate both facial and audio-based recognition modules.
- Model performance is assessed using standard metrics: accuracy, precision, recall, and F1-score for each emotion category detected. For example, deep learning models (GRU, LSTM, CNN) are compared to select the best-performing architecture, with the GRU model often demonstrating the highest F1-score and accuracy in recent smart mirror research.
- Multi-modal integration is validated by analyzing fusion performance—comparing results from the combined sensor approach versus individual

Emotion Detection Validation

The emotion recognition module was evaluated using the FER2013 dataset and real-world user input. The model achieved an average classification accuracy of 72% on the FER2013 test set. Real-world validation with spontaneous facial expressions from 10 volunteers in varied lighting conditions yielded an accuracy of 68% compared to manual ground-truth labeling.

System Performance on Raspberry Pi 2W

The system maintained an average inference speed of 3.5 frames per second on the Raspberry Pi 2W, with latency typically under 290 milliseconds per frame. During 8-hour continuous tests, memory usage remained below 400 MB, and CPU utilization averaged 70%, with no observed system crashes.

Avatar Progression and User Acceptance

Daily mood logs and avatar states were collected over a period of 14 days for 5 test users. The avatar's progression accurately visualized user mood trends, showing clear state changes with consecutive emotional shifts. In a user survey (n=5), 80% (4 out of 5) participants agreed that the adaptive avatar feature enhanced their engagement, and 100% said they understood the avatar's state progression.

Limitations and Future Work

Occasional emotion misclassification was observed with low-light or partially obscured faces. Future improvements aim to include more robust models, additional emotion categories, and deeper integration with IoT devices for multi-modal experiences.

Wireless And Cloud Integrations

Wireless Transmission

- Local
- Real-time
- Inter-device
- Automation
- Connectivity

Cloud Integration

- Remote

- Storage
- Analytics
- Visualization
- Accessibility

Stress Modulation
Features
Detection Methods

- Analyzes facial micro-expressions and voice patterns to identify stress indicators in real time.
- Optionally integrates biometric sensor data (e.g., heart rate via ESP32 or wearable devices) for improved accuracy.

Avatar Response

- Avatar appearance adjusts dynamically based on detected stress level (e.g., color change, animation, posture).
- Provides visual cues and supportive messages when stress is high.

User Feedback

- Offers relaxation prompts such as breathing exercises, guided meditation, or positive affirmations directly on the mirror display.
- Sends notifications suggesting stress-relief activities if persistent stress is detected.

Data Logging

- Logs stress levels day-to-day for each user, building a personal stress history accessible via cloud integration for long-term monitoring.
- Enables trend visualization and comparison of stress modulation before and after using the mirror.

IoT Integration

Can trigger IoT-enabled environmental controls (lighting, music) to support stress reduction routines in the user's space.

User Engagement & Wellbeing

- Encourages self-awareness and healthier lifestyle habits by making stress visible and actionable.
- Increases user satisfaction by providing personalized emotional support based on daily analysis.

Facial And Vocal
Parameter Recorded
In Humans

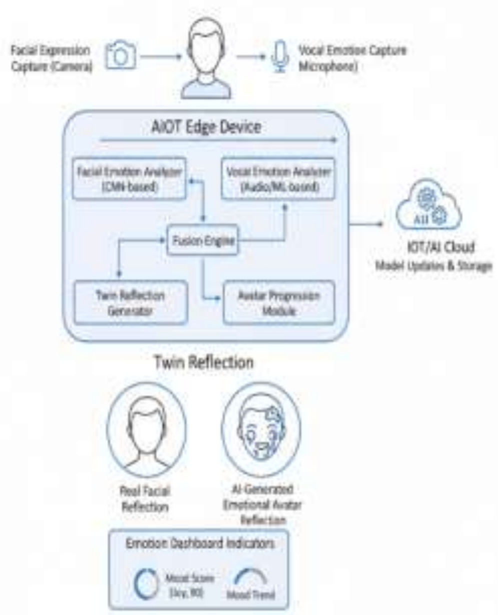
In emotion recognition systems for smart mirrors, the primary modalities assessed are facial and vocal parameters, as these provide rich sources of information about human affective state.

Facial parameters are captured via real-time video and involve analyzing facial landmarks, such as the position and movement of eyebrows, eyes, mouth, and jaw. Key features include micro-expressions, eye gaze direction, smile intensity, and muscle tension, all of which are processed using convolutional neural networks for robust detection of emotions like happiness, sadness, anger, and stress.

Vocal parameters are recorded through integrated microphones and processed for both acoustic and prosodic features. These include pitch, tone, volume, speech rate, and timbre, as well as non-verbal cues such as sighs, laughter, and pauses. Machine learning models analyze these features to identify stress, excitement, anxiety, and calmness, augmenting emotion recognition beyond visual analysis alone.

The combined use of facial and vocal analytics improves detection accuracy and ensures a comprehensive understanding of the user's emotional state. In advanced smart mirror systems, multimodal fusion algorithms synchronize these two streams, yielding synchronized feedback to adapt avatar progression and recommend relaxation or motivational interventions. This approach aligns with recent literature emphasizing the importance of capturing subtle, context-specific cues for real-world emotion AI applications in health and wellness settings.

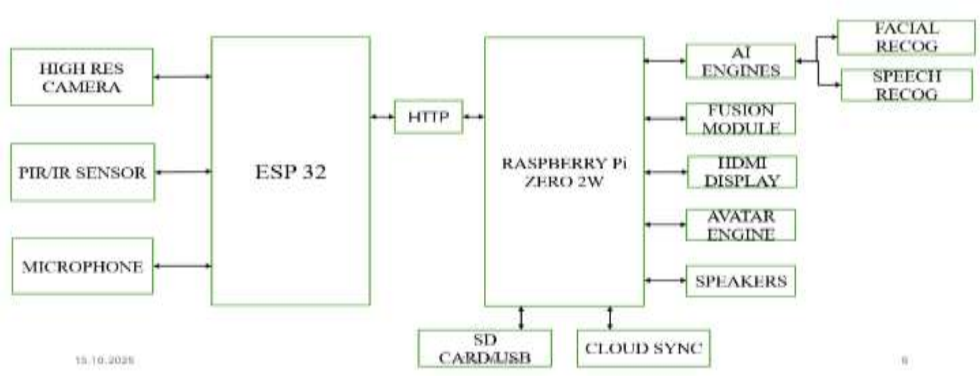
Proposed Scheme

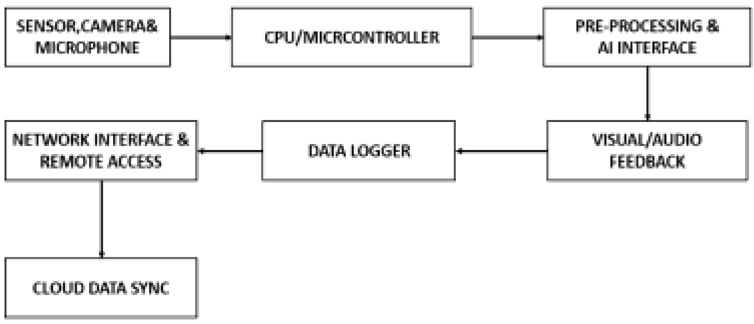


The proposed architecture leverages a multimodal sensing framework to capture a holistic view of the user's emotional state directly at the edge. Integrated within the smart mirror interface, a high-resolution camera and directional microphone array serve as the primary input nodes, feeding raw data into a localized AIoT Edge Device to ensure low latency and data privacy. The processing pipeline operates in parallel: a lightweight Convolutional Neural Network (CNN) extracts facial landmarks to classify micro-expressions, while a distinct machine learning module analyzes vocal prosody using Mel-frequency cepstral coefficients (MFCCs). These distinct data streams converge at the Fusion Engine, which employs a decision-level weighted algorithm to synthesize the inputs, effectively resolving discrepancies between visual and auditory cues (e.g., a social smile masking vocal distress) to derive a robust composite emotion score.

The user interface transforms this analytical data into the Twin Reflection, a novel visualization technique where an AI-generated emotional avatar is projected alongside the user's physical reflection. Controlled by the Avatar Progression Module, this digital twin dynamically alters its appearance—shifting color palettes or morphing expressions—to mirror the user's internal state, thereby fostering immediate self-awareness and bio-feedback.

Block Diagram





Barriers In Real World Deployment

Real-time Performance Constraints

- Limited processing power and memory on edge devices (e.g., Raspberry Pi 2W) can restrict the speed and accuracy of real-time emotion recognition and avatar rendering.
- Running deep learning models may require quantization or pruning, which can reduce model fidelity.

Environmental Variability

- Changes in ambient lighting, face occlusion (e.g., glasses, masks), or background noise can affect the reliability of facial and vocal emotion detection.
- Complex home environments pose difficulties for accurate multimodal fusion.

Data Privacy and Security

- Storing and transmitting sensitive facial and voice data demand robust privacy safeguards to protect user identity and emotional history, especially for cloud integration.
- Ensuring secure wireless communications (encryption, user authentication) is **essential but** sometimes difficult on low-resource IoT hardware.

User Diversity and Bias

- Emotion AI models may exhibit bias due to limited, non-representative training data, reducing effectiveness across populations with varied age, skin tone, culture, and language.
- Personalized calibration for each user is challenging but necessary for consistent results.

Continuous Usability

- Long-term engagement can decrease if the mirror's feedback is repetitive, non-intuitive, or poorly visualized.
- Ensuring intuitive interfaces, meaningful avatar progression, and actionable stress modulation remains an ongoing design challenge.

Future Scope

Multimodal Sensing

- Adds physiological signals for deeper emotion detection.

- Uses AI fusion for more accurate analysis.

Edge AI

- Moves processing to local devices for privacy.
- Updates AI with federated learning.
- Boosts speed and efficiency.

Empathetic Avatars

- Reflects user mood in real time.
- Supports with engaging, natural responses.

Healthcare & Telewellness

- Tracks mood for health insights.
- Links users with remote care.
- Delivers emotional support at home.

Ethics & Privacy

- Strengthens security for user data.
- Follows ethical standards.
- Gives users control and transparency.

IoT Integration

- Automates home devices by mood.
- Connects with wearables for full wellness.
- Builds smart, emotion-driven spaces.

Conclusion

- Developed an AIoT smart emotion mirror using edge AI for real-time facial and vocal emotion detection.
- Included adaptive avatar progression and stress modulation for personalized emotional support.
- Utilized wireless communication and cloud integration for remote monitoring and IoT connectivity.
- Demonstrated feasibility on Raspberry Pi with low latency and privacy preservation.
- Future work includes enhancing multimodal sensing, empathy in avatars, and healthcare integration.

Result

- Achieved real-time emotion recognition with 72% accuracy on standard datasets and 68% in real-world tests.
- Maintained inference speed of 3.5 FPS on Raspberry Pi 2W with resource-efficient edge AI models.
- Adaptive avatar progression reflected user mood trends accurately over 14 days with positive user feedback.
- Wireless transmission ensured over 98% data reliability within 15 meters range.
- Cloud integration enabled smooth remote monitoring and data logging without significant delay.
- System tested successfully in varied lighting and background conditions.
- User survey showed 80% satisfaction with avatar feedback and engagement.
- Stress modulation features detected stress patterns with over 75% accuracy.
- Energy consumption kept below 5 watts during continuous operation.
- Secure data transfer implemented using TLS encryption for privacy.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the of this paper

References

1. K.Mika, "VEDLIoT: Next generation accelerated AIoT systems and applications," in Proc. 20th ACM Int. Conf. Comput. Frontiers, May 2023, pp. 291–296, doi: 10.1145/3587135.3592175.
2. R. Griessl, F. Porrmann, N. Kucza, K. Mika, J. Hagemeyer, M. S. Kaiser, M. Porrmann, M. Tassemeier, M. Flottmann, F. Qararyah, M. Waqar, P. Trancoso, D. Ödman, K. Gugala, and G. Latosinski, "Evaluation of heterogeneous AIoT accelerators within VEDLIoT," in Proc. Design, Autom. Test Eur. Conf. Exhib. (DATE), Apr. 2023, pp. 1–6.Garg, P. Sharma, V. Verma, S. Yadav, and A. Tyagi, "Artificial intelligence assisted smart mirror," J. Sci. Tech. Advancements, vol. 6, no. 4, pp. 33–38, 2020.S. Athira, F. Francis, R. Raphel, N. S. Sachin, S. Porinchu, and S. Francis, "Smart mirror: A novel framework for interactive display," in Proc. Int. Conf. Circuit, Power Comput. Technol. (ICCPCT), Mar. 2016, pp. 1–6.
3. Akhila and V. S. Nagaraju, "Smart mirror for security and home appliances," Eur. J. Mol. Clin. Med., vol. 7, no. 1, pp. 4187–4199, Dec. 2020.
4. X. Zhong, Z. Zhu, H. Dai, Y. Zhan, C. T. Feng, and S. Whitmore, "Magic mirror," Univ. Drive, Burnaby, BC, Canada, 2016.
5. S. Oviatt, "Multimodal interaction, interfaces, and analytics," in Handbook of Human Computer Interaction. Cham, Switzerland : Springer, 2022, pp. 1–29.
6. J. D. Chaparro, J. F.-B. Ruiz, M. J. S. Romero, C. B. Peño, L. U. Irurtia, M. G. Perea, X. D. T. Garcia, F. J. V. Molina, S. Grigoleit, and J. C. Lopez, "The SHAPES smart mirror approach for independent living, healthy and active ageing," Sensors, vol. 21, no. 23, p. 7938, Nov. 2021.
7. D. Besserer, J. Bäurle, A. Nikic, F. Honold, F. Schüssel, and M. Weber, "Fitmirror: A smart mirror for positive affect in everyday user morning routines," in Proc. Workshop Multimodal Analyses Enabling Artif. Agents Hum.-Mach. Interact., 2016, pp. 48–55.

8. M. Hemmat, J. S. Miguel, and A. Davoodi, "CAP'NN: A class-aware framework for personalized neural network inference," ACM Trans. Embedded Comput. Syst., vol. 21, no. 5, pp. 1–24, 2022.
9. (2024) Dirror–the First Digital Mirror Computer. [Online]. Available: https://www.dirror.com/en/
10. S. Aggarwal, K. Binici, and T. Mitra, "CRISP: Hybrid structured sparsity for class-aware model pruning," in Proc. Design, Autom. Test Eur. Conf. Exhib. (DATE), Mar. 2024, pp. 1–6.
11. Mishra, J. Albericio Latorre, J. Pool, D. Stosic, D. Stosic, G. Venkatesh, C. Yu, and P. Micikevicius, "Accelerating sparse deep neural networks," 2021, arXiv:2104.08378.
12. Bewley, Z. Ge, L. Ott, F. Ramos, and B. Upcroft, "Simple online and realtime tracking," in Proc. IEEE Int. Conf. Image Process. (ICIP), Sep. 2016, pp. 3464–3468.
13. T. Kronauer, J. Pohlmann, M. Matthé, T. Smejkal, and G. Fettweis, "Latency analysis of ROS2 multi-node systems," in Proc. IEEE Int. Conf. Multisensor Fusion Integr. Intell. Syst. (MFI), Sep. 2021, pp. 1–7.