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Leveraging Digital Twin and Generative AI to Alleviate Loneliness Among Elderly Adults Living Alone Through Smart Flowerpot Design

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ABSTRACT

Loneliness and social isolation among elderly adults contribute to aging-related diseases, necessitating personalized interventions. Despite various approaches—social robots, group activities, serious games, and chatbots—adaptability to individual needs remains a challenge. This research introduces a smart flowerpot, integrating generative AI, digital twin, and reconfigurable design to create personalized interventions within a smart service ecosystem. Equipped with IoT sensors, the flowerpot detects user presence, interacts with the user digital twin, and adapts its responses through AI-generated efficacy intervention. Qualitative evaluations suggest the concept of smart flowerpot can enhance the user's engagement and well-being, offering a novel approach to elderly care.

Keywords: Elderly loneliness, Smart service design, Human digital twin, Generative AI, Personalized interventions

INTRODUCTION

With the intensification of global aging, the issues of loneliness and social isolation among the elderly are becoming increasingly prominent. Loneliness not only affects the mental health of older adults but is also closely associated with various aging-related diseases, such as depression, cardiovascular disease, and cognitive decline (Teguo et al., 2016). In response to these challenges, recent studies, including "Mitigating Social Isolation and Loneliness Through Smart Technology for Aging-in-Place" (Durak, 2024), have explored the role of smart technology in alleviating loneliness and enhancing social engagement among older adults. As research in this field continues to expand, developing effective strategies to mitigate elderly loneliness remains a crucial area of study.

The primary challenge in addressing loneliness and social isolation among elderly adults is the development of interventions that can adapt to the unique personal needs, environments, and contexts of individuals. Current interventions often lack the flexibility required to provide personalized and sustained support. For example, while social robots can provide companionship, they may not adapt to the changing emotional states or preferences of the user over time (Blanco et al., 2024). Loneliness and social isolation are prevalent among elderly adults, with significant implications for their physical and mental health. Research has shown that these conditions are associated with increased risks of depression, cognitive decline, and mortality (Cacioppo & Cacioppo, 2018). The COVID-19 pandemic has further exacerbated these issues, as many elderly individuals were forced to isolate themselves to avoid health risks.

Various interventions have been developed to address loneliness and social isolation, including social robots, group activities, serious games, and chatbots. While these interventions have shown some success, they often lack the adaptability required to meet the diverse needs of elderly individuals. For example, social robots like PARO have been used to provide companionship, but they are limited in their ability to adapt to the changing emotional states of users (Shibata & Wada, 2011).

Digital twin (DT) technology involves creating a virtual replica of a physical entity, enabling real-time monitoring and analysis. This technology has been widely used in industries such as manufacturing and healthcare to optimize processes and improve outcomes (Grieves, 2014). Generative AI, on the other hand, involves the use of algorithms to generate new content, such as text, images, and music. The integration of these technologies offers new possibilities for personalized interventions, particularly in the context of elderly care.

DT is being applied in healthcare on a growing scale to enable real-time monitoring, predictive diagnosis, and tailored care plans (Venkatesh et al., 2023). In elderly care, DT is capable of simulating an individual's daily activities, detecting anomalies in behavior, and adjusting care interventions accordingly (Lazarev & Kalininskaya, 2024). With IoT sensors embedded in intelligent environments and wearables, DT and AI-enabled intervention systems can better support independent living in older adults by minimizing the dangers of social isolation and promoting adaptive care practices.

Moreover, generative AI has been used increasingly to enable improved human-AI interaction through dynamic, emotionally intelligent dialogue. Research indicates that conversational agents based on AI improve engagement and mental well-being in older adults through companionship and cognitive stimulation (Shimizu et al., 2024). The AI models have also been proved to reduce caregiver stress by automating tailored interventions in healthcare, thus streamlining care processes without neglecting personalized care (Khan et al., 2024). One study recently tested AI-driven photo-based dialogues, where older adults engaged meaningfully with AI agents capable of scanning photos and offering conversational prompts. Findings suggest that older adults respond positively to AI that simulates humans, further proving that AI-driven social interventions have the potential to enhance emotional well-being (Shimizu et al., 2024).

However, the challenges of making the DT and AI-enabled interventions acceptable by the older users are twofold. First, the intervention service interfaces need as natural as possible for delivering useful functions. And the second is to have good means to address personal data and privacy concerns.

To meet these challenges, we propose a smart flowerpot solution situated in a home environment to provide useful interventions to the user via natural interactions and serve as an information hub connecting with the user's personal digital twin to facilitate various interventions among, the user, the flowerpot, the user's caregivers, and the community support services. In this paper, we first review users pain points in their daily life when living along, existing interventions and their limitations. Then we conduct a conceptual design of the smart flowerpot and its qualitative evaluation via a Focus group. And finally, we discuss its potential future work.

RELATED WORK

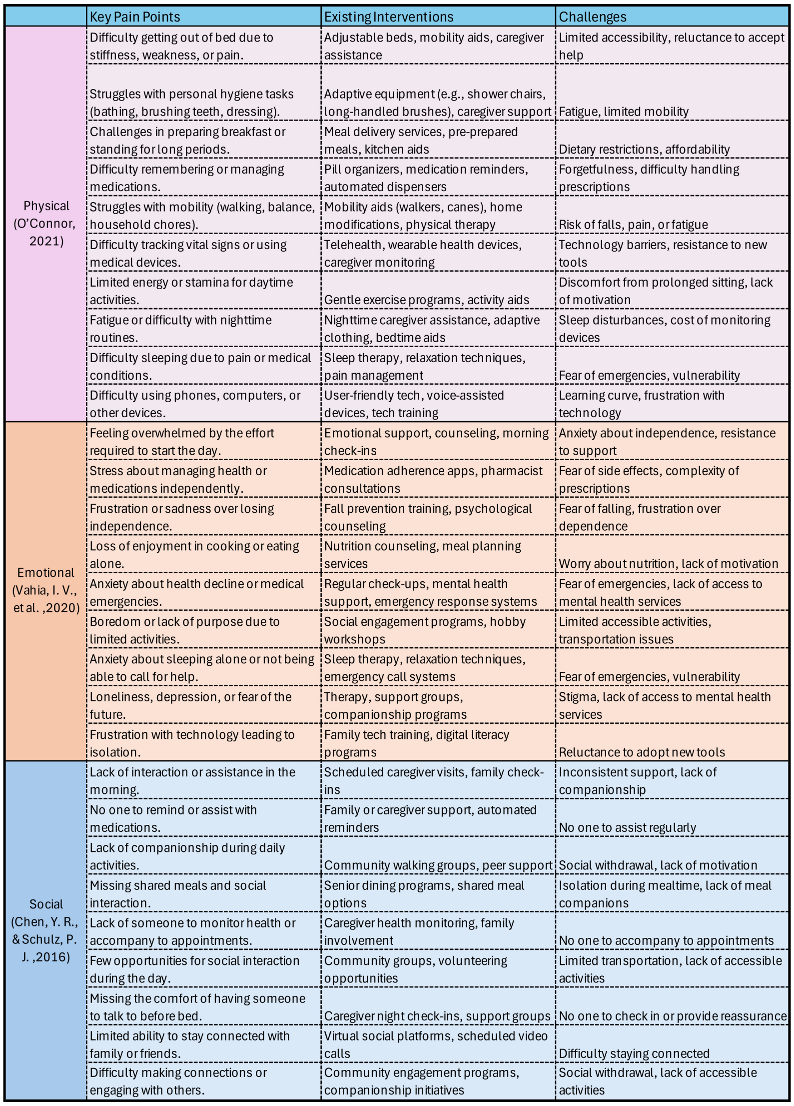
Recent advancements in machine learning and AI have significantly impacted healthcare, particularly predictive analytics, patient monitoring, and elderly care. Hospital readmissions have been increasingly being predicted through machine learning models based on EHR and wearable sensor data analysis, improving earlier intervention and reducing healthcare costs (Shickel et al., 2018). AI-driven systems, for instance, CarePredict, leverage wearable sensors to monitor daily activities and detect behavior anomalies, such as falls and abnormal patterns of change in movements, thus enhancing patient safety and detection of deteriorating health at an earlier point (CarePredict, 2023). AI chatbots, for example, Medisafe, deliver personalized reminders on medications and education to facilitate drug adherence, addressing one of the largest challenges in elderly care (Medisafe, 2022).

At the same time, intelligent healthcare devices have been on the increase in elderly care systems. Intelligent pill dispensers, for instance, such as Hero, apply machine learning to learn users' drug regimens and remind users in real time, encouraging compliance and minimizing the likelihood of human errors (Hero Health, 2023). Social robots, too, such as ElliQ, with NLP abilities, interact with older adults daily and assist in maintaining social connections, basically easing feelings of loneliness and isolation (Intuition Robotics, 2023). Beyond social interaction, conversational agents based on AI, such as Woebot, provide cognitive behavior therapy (CBT) to patients with depression and anxiety, demonstrating the potential of AI in mental care interventions (Fitzpatrick et al., 2017).

AI-driven computer vision technologies have also enhanced fall detection and monitoring in real time. Intelligent home cameras' video streams are now processed by deep learning algorithms to detect falls with high accuracy, reducing emergency response times significantly (Aziz et al., 2021). Similarly, wearable devices such as the Apple Watch feature AI-driven fall detection features, automatically initiating emergency calls when sudden falls occur (Apple, 2023). Outside of personal monitoring, AI systems such as IBM Watson Health scan large EHR data collections to recommend customized treatment plans, optimizing medical decision-making and outcomes (IBM, 2023). Moreover, predictive analytics solutions have been applied to identify high-risk patients, enabling healthcare professionals to implement preventive interventions in advance (Rajkomar et al., 2019).

AI voice assistants have also been effective tools in elderly care. Intelligent devices such as Amazon's Alexa and Google Home enable older adults to carry out daily tasks, remind them of appointments, and change intelligent home settings using voice commands, hence enhancing accessibility and convenience (Amazon, 2023). AI systems such as SafelyYou also utilize computer vision to continuously detect and prevent falls, offering a proactive solution to elderly safety in home and institutional care (SafelyYou, 2023).

Despite all these technological advances, several challenges remain in the adoption and utilization of AI-driven healthcare solutions. Issues of data security and privacy are some of the major concerns, as AI systems require constant data collection and processing, which creates issues of consent and confidentiality. Additionally, technological illiteracy concerns with elderly patients have also been a hindrance to adoption, as elderly patients struggle to navigate AI-enabled systems. The cost of intelligent devices, as well as compatibility issues with existing healthcare infrastructures, also limit accessibility and scalability. More importantly, current research is unable to provide personalized services with natural interactions. The key pain points, existing interventions and their challenges are summarized in Figure 1.

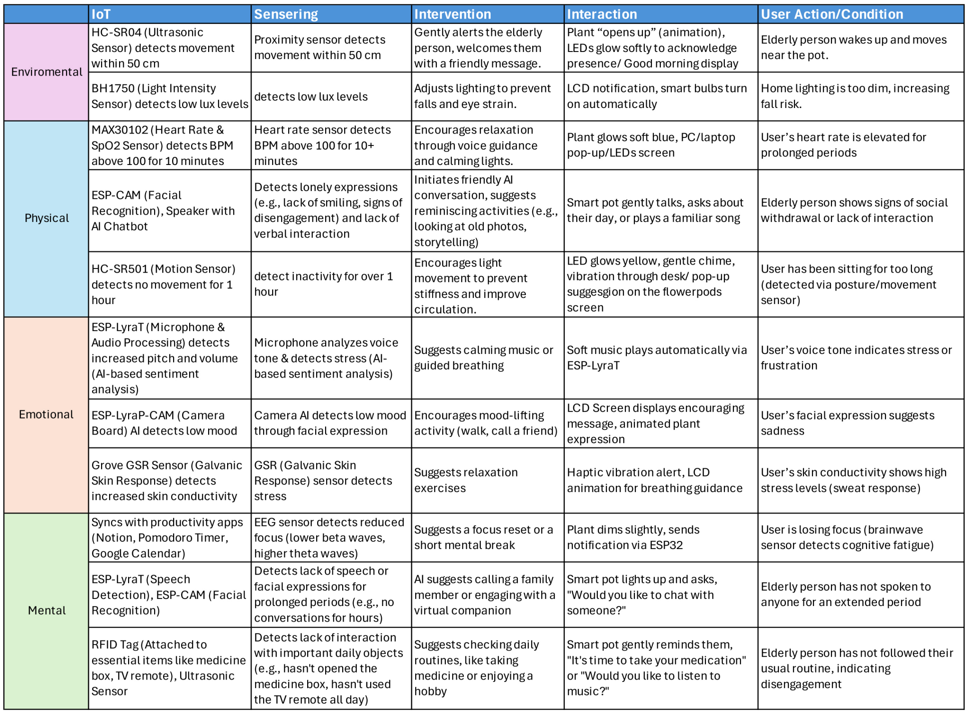


	Key Pain Points	Existing Interventions	Challenges
Physical (O'Connor, 2021)	Difficulty getting out of bed due to stiffness, weakness, or pain.	Adjustable beds, mobility aids, caregiver assistance	Limited accessibility, reluctance to accept help
	Struggles with personal hygiene tasks (bathing, brushing teeth, dressing).	Adaptive equipment (e.g., shower chairs, long-handled brushes), caregiver support	Fatigue, limited mobility
	Challenges in preparing breakfast or standing for long periods.	Meal delivery services, pre-prepared meals, kitchen aids	Dietary restrictions, affordability
	Difficulty remembering or managing medications.	Pill organizers, medication reminders, automated dispensers	Forgetfulness, difficulty handling prescriptions
	Struggles with mobility (walking, balance, household chores).	Mobility aids (walkers, canes), home modifications, physical therapy	Risk of falls, pain, or fatigue
	Difficulty tracking vital signs or using medical devices.	Telehealth, wearable health devices, caregiver monitoring	Technology barriers, resistance to new tools
	Limited energy or stamina for daytime activities.	Gentle exercise programs, activity aids	Discomfort from prolonged sitting, lack of motivation
	Fatigue or difficulty with nighttime routines.	Nighttime caregiver assistance, adaptive clothing, bedtime aids	Sleep disturbances, cost of monitoring devices
	Difficulty sleeping due to pain or medical conditions.	Sleep therapy, relaxation techniques, pain management	Fear of emergencies, vulnerability
	Difficulty using phones, computers, or other devices.	User-friendly tech, voice-assisted devices, tech training	Learning curve, frustration with technology
Emotional (Vahia, I. V., et al. ,2020)	Feeling overwhelmed by the effort required to start the day.	Emotional support, counseling, morning check-ins	Anxiety about independence, resistance to support
	Stress about managing health or medications independently.	Medication adherence apps, pharmacist consultations	Fear of side effects, complexity of prescriptions
	Frustration or sadness over losing independence.	Fall prevention training, psychological counseling	Fear of falling, frustration over dependence
	Loss of enjoyment in cooking or eating alone.	Nutrition counseling, meal planning services	Worry about nutrition, lack of motivation
	Anxiety about health decline or medical emergencies.	Regular check-ups, mental health support, emergency response systems	Fear of emergencies, lack of access to mental health services
	Boredom or lack of purpose due to limited activities.	Social engagement programs, hobby workshops	Limited accessible activities, transportation issues
	Anxiety about sleeping alone or not being able to call for help.	Sleep therapy, relaxation techniques, emergency call systems	Fear of emergencies, vulnerability
	Loneliness, depression, or fear of the future.	Therapy, support groups, companionship programs	Stigma, lack of access to mental health services
	Frustration with technology leading to isolation.	Family tech training, digital literacy programs	Reluctance to adopt new tools
Social (Chen, Y. R., & Schulz, P. J. ,2016)	Lack of interaction or assistance in the morning.	Scheduled caregiver visits, family check-ins	Inconsistent support, lack of companionship
	No one to remind or assist with medications.	Family or caregiver support, automated reminders	No one to assist regularly
	Lack of companionship during daily activities.	Community walking groups, peer support	Social withdrawal, lack of motivation
	Missing shared meals and social interaction.	Senior dining programs, shared meal options	Isolation during mealtime, lack of meal companions
	Lack of someone to monitor health or accompany to appointments.	Caregiver health monitoring, family involvement	No one to accompany to appointments
	Few opportunities for social interaction during the day.	Community groups, volunteering opportunities	Limited transportation, lack of accessible activities
	Missing the comfort of having someone to talk to before bed.	Caregiver night check-ins, support groups	No one to check in or provide reassurance
	Limited ability to stay connected with family or friends.	Virtual social platforms, scheduled video calls	Difficulty staying connected
	Difficulty making connections or engaging with others.	Community engagement programs, companionship initiatives	Social withdrawal, lack of accessible activities

Figure 1: Common pain points, existing interventions and challenges.

SMART FLOWERPOT CONCEPTIAL DESIGN

The integration of artificial intelligence (AI) into everyday objects has paved the way for innovative solutions in elderly care, with the smart flowerpot emerging as a holistic system that combines emotion detection, health monitoring, social interaction, and plant care assistance. This design leverages AI-driven analytics, IoT sensors, and an intuitive user interface to enhance the well-being of elderly users. A key feature of the smart flowerpot is its ability to detect emotions through IoT and DT, which analyze the context. AI models process these inputs to infer emotional states, prompting the flowerpot to respond with calming LED lights, soothing sounds, or gentle movements. Additionally, health monitoring is facilitated through sensors that measure heart rate, temperature, and air quality, with AI algorithms analyzing these data points to detect anomalies (see Figure 2). In the event of irregularities, timely alerts are sent to caregivers, enabling early intervention and improved safety.



	IoT	Sensering	Intervention	Interaction	User Action/Condition
Enviromental	HC-SR04 (Ultrasonic Sensor) detects movement within 50 cm	Proximity sensor detects movement within 50 cm	Gently alerts the elderly person, welcomes them with a friendly message.	Plant “opens up” (animation), LEDs glow softly to acknowledge presence/ Good morning display	Elderly person wakes up and moves near the pot.
	BH1750 (Light Intensity Sensor) detects low lux levels	detects low lux levels	Adjusts lighting to prevent falls and eye strain.	LCD notification, smart bulbs turn on automatically	Home lighting is too dim, increasing fall risk.
Physical	MAX30102 (Heart Rate & SpO2 Sensor) detects BPM above 100 for 10 minutes	Heart rate sensor detects BPM above 100 for 10+ minutes	Encourages relaxation through voice guidance and calming lights.	Plant glows soft blue, PC/laptop pop-up/LEDs screen	User’s heart rate is elevated for prolonged periods
	ESP-CAM (Facial Recognition), Speaker with AI Chatbot	Detects lonely expressions (e.g., lack of smiling, signs of disengagement) and lack of verbal interaction	Initiates friendly AI conversation, suggests reminiscing activities (e.g., looking at old photos, storytelling)	Smart pot gently talks, asks about their day, or plays a familiar song	Elderly person shows signs of social withdrawal or lack of interaction
	HC-SR501 (Motion Sensor) detects no movement for 1 hour	detect inactivity for over 1 hour	Encourages light movement to prevent stiffness and improve circulation.	LED glows yellow, gentle chime, vibration through desk/ pop-up suggesgion on the flowerpods screen	User has been sitting for too long (detected via posture/movement sensor)
Emotional	ESP-LyraT (Microphone & Audio Processing) detects increased pitch and volume (AI-based sentiment analysis)	Microphone analyzes voice tone & detects stress (AI-based sentiment analysis)	Suggests calming music or guided breathing	Soft music plays automatically via ESP-LyraT	User’s voice tone indicates stress or frustration
	ESP-LyraP-CAM (Camera Board) AI detects low mood	Camera AI detects low mood through facial expression	Encourages mood-lifting activity (walk, call a friend)	LCD Screen displays encouraging message, animated plant expression	User’s facial expression suggests sadness
	Grove GSR Sensor (Galvanic Skin Response) detects increased skin conductivity	GSR (Galvanic Skin Response) sensor detects stress	Suggests relaxation exercises	Haptic vibration alert, LCD animation for breathing guidance	User’s skin conductivity shows high stress levels (sweat response)
Mental	Syncs with productivity apps (Notion, Pomodoro Timer, Google Calendar)	EEG sensor detects reduced focus (lower beta waves, higher theta waves)	Suggests a focus reset or a short mental break	Plant dims slightly, sends notification via ESP32	User is losing focus (brainwave sensor detects cognitive fatigue)
	ESP-LyraT (Speech Detection), ESP-CAM (Facial Recognition)	Detects lack of speech or facial expressions for prolonged periods (e.g., no conversations for hours)	AI suggests calling a family member or engaging with a virtual companion	Smart pot lights up and asks, "Would you like to chat with someone?"	Elderly person has not spoken to anyone for an extended period
	RFID Tag (Attached to essential items like medicine box, TV remote), Ultrasonic Sensor	Detects lack of interaction with important daily objects (e.g., hasn't opened the medicine box, hasn't used the TV remote all day)	Suggests checking daily routines, like taking medicine or enjoying a hobby	Smart pot gently reminds them, "It's time to take your medication" or "Would you like to listen to music?"	Elderly person has not followed their usual routine, indicating disengagement

Figure 2: Functions of the smart flowerpot.

Beyond health monitoring, the smart flowerpot functions as a medication reminder, synchronizing with a mobile application to provide subtle visual or auditory cues, ensuring adherence to medication schedules. Social interaction is further enhanced through an integrated voice assistant, enabling natural conversations and facilitating message exchange with family members, who can send photos, text, or voice notes. These messages can either be displayed on a screen or read aloud, fostering a sense of connection and reducing social isolation. In addition to its role in human interaction, the smart flowerpot assists in plant care by monitoring soil moisture, light, and temperature levels, offering personalized care recommendations to encourage user engagement and a sense of responsibility.

Designed for intuitive and accessible interaction, the smart flowerpot enables users to engage through voice commands, LED signals, and gentle vibrations. Accessibility features, such as large manual buttons, voice feedback for visually impaired users, and a simplified setup process, ensure ease of use, particularly for older adults with cognitive or physical limitations. To foster emotional engagement, personalization options allow users to name their flowerpot and select from various AI-generated personalities, while growth feedback features provide notifications on plant development, reinforcing a sense of achievement and companionship.

The hardware components of the smart flowerpot include sensors for soil moisture, temperature, heart rate, and emotion along with actuators that enable dynamic responses such as adjusting lighting, playing sounds, or initiating gentle movement (see Figure 3 and Figure 4). AI algorithms process real-time data to optimize emotion recognition, health monitoring, and plant care recommendations, while cloud-based infrastructure ensures secure data storage, remote monitoring, and seamless caregiver communication. Figure 3 indicates some IoT sensors design for support the above functions realization. Figure 4 shows the system framework.

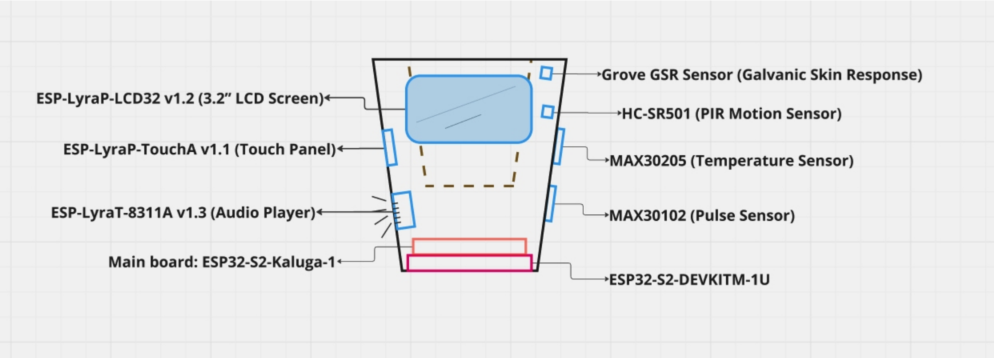


Figure 3: Sketch of the smart flowerpot structure.

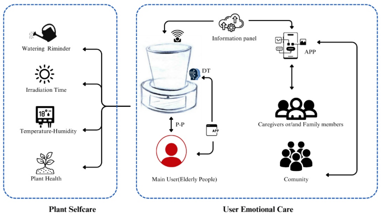


Figure 4: Framework of the smart flowerpot system.

QUALITATIVE EVALUATION

A qualitative evaluation of our conceptual design was conducted with a Focus group in a controlled laboratory setting to assess the initial functionality of the smart flowerpot, ensuring that its design, structure, embedded sensors, and interactive features operated as intended. This focus group studied involved researchers and developers testing core components, including emotion detection, health monitoring, and social interaction capabilities. The primary objective was to verify system responsiveness, sensor accuracy, and AI-driven interactions before engaging end users in a more iterative, user-centred design process. Preliminary findings confirmed that the integrated sensors effectively captured environmental and physiological data, with heart rate, and soil moisture measurements aligning with expected outputs. The emotion detection system responded to distinct facial expressions and voice modulations and biological data, activating corresponding interventions such as LED adjustments and audio feedback. However, inconsistencies in detecting subtle emotional states highlighted the need for further refinement in AI processing. Additionally, leveraging DT technology to better understand user context and implementing GAI for personalized interactions require deeper exploration to enhance adaptability and responsiveness. Further research is needed to optimize these technologies, ensuring a more intuitive and context-aware user experience.

Despite the overall success of the conceptual design validation, areas for improvement emerged. The accuracy of emotion recognition requires optimization to minimize misclassification, and the responsiveness of the voice assistant needs enhancement for smoother interactions. Adjustments to sensor calibration are also identified to ensure long-term stability. Additionally, while the design effectively concealed embedded technology, further refinements in material selection and form factor have been suggested to enhance aesthetic appeal and usability.

These insights provide a foundation for the next phase, which will adopt a user-centred and co-design approach with elderly participants to refine interaction models, personalize AI responses, and ensure the system aligns with real-world user needs. By integrating direct user feedback, future iterations will enhance accessibility, engagement, and ethical considerations, ultimately improving the smart flowerpot's effectiveness as a supportive tool for elderly well-being.

DISCUSSION

The qualitative evaluation of the smart flowerpot prototype revealed that the system has significant potential to enhance user understanding, engagement, and experience. Participants reported feeling more connected and engaged with the flowerpot, and appreciated the personalized interventions. Many participants believe that the flowerpot can provide a sense of companionship and reduce feelings of loneliness. Some participants suggest additional features, such as the ability to customize the flowerpot's appearance or integrate it with other smart home devices.

While the results are promising, there are some limitations to the study. The sample size was relatively small, and further research is needed to evaluate the effectiveness of the smart flowerpot via its further developed functional prototypes in terms of alleviating loneliness and social isolation.

This paper presents the conceptual design of a smart flowerpot, and its development framework for evaluating its effectiveness and usability. Our future work is to apply user-centred design processes and methods to further develop functional prototypes for evaluation and feedback in an iterative improvement process. The functional prototypes of the user digital twins and AI tools will be integrated into our future research work.

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