Towards Personal Robotics: An Analysis of the State of the Art

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Abstract

The field of social robotics is progressing swiftly, focusing on robots that can engage with humans in significant ways in home or domestic environments such as education or eldercare. Social robots are increasingly becoming tools dedicated to individuals and are being used as pervasive instruments in everyday life. Therefore, it is necessary to address the concept of personal social robots which has not been widely explored. For example, not all social robots can be classified as personal robots. This paper begins with an analysis of the applications of the most commonly used social robots—Alpha Mini, NAO, Cozmo and Vector, and PARO—that have the potential to function as personal social robots. Despite the diversity of applications, software architectures, and the variety of contexts in which personal robots are employed, we believe it is essential to develop a general software architecture for personal robots. Such architecture should enable interaction with people across different contexts, purposes, and applications.

Keywords

Social Assistive Robots, Personal Robots, Robot Architectures

1. Introduction

Social robotics is a rapidly advancing field focused on the development of robots capable of interacting with humans in meaningful ways, enhancing their quality of life. These robots, designed to address both social and emotional needs, have found applications in diverse areas such as eldercare, education, and support for disabled individuals. By providing tailored interactions and fostering engagement, social robots not only represent practical assistants but also serve as companions capable of forming meaningful relationships and improving overall well-being [1]. In particular, social robots have demonstrated their potential in promoting communication and emotional development among children, offering companionship and cognitive stimulation to older adults, and enhancing the autonomy and quality of life of individuals with specific needs. Advances in artificial intelligence and interaction technologies further enhance their adaptability and effectiveness, making them valuable tools in personal and domestic contexts. Social robots are also becoming increasingly significant in promoting the well-being of older adults, addressing challenges such as cognitive decline, loneliness, nutritional frailty, and engagement in interactive activities. By offering tailored interventions, companionship, empathetic responses [2], and cognitive stimulation [3, 4, 5], these robots enhance the quality of life and support independent living for seniors.

Our focus will center on the requirements of at-risk populations, including children, the elderly, autistic individuals, and disabled people, along with vulnerable groups like refugees and immigrants. This research aims to shed light on the abilities and contributions of prominent social robots, such as Alpha Mini, NAO, Cozmo and Vector, and PARO by examining their current uses in education and elderly care.

This paper investigates the cutting-edge software architectures utilized in personal social robots, emphasizing: i) their abilities in natural interaction; ii) and the analysis of user conversations. The objective is to delve into how these systems interpret and analyze user input to develop dynamic user

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profiles, facilitating personalized and adaptive behaviors that encourage social and cultural inclusion for a varied user demographic understanding how recent implementations of software architectures for social robots are suitable for home and personal use. Software architectures have also been analyzed considering interactions and increase inclusion in a variety of social and cultural contexts.

2. Alpha Mini

This section explores the applications of the UBTECH Alpha Mini (Figure 1) at the state of the art. This versatile robot is equipped with an extensive array of sensors and features, including the ability to speak, display emotions via its LCD eyes, and perform various actions. These capabilities make it well-suited for fostering meaningful interactions and providing support in a variety of social and daily contexts.

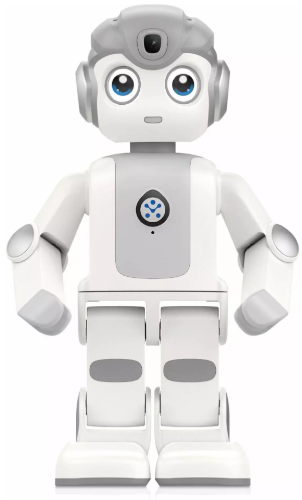

Figure 1: Alpha Mini - UBTECH Robotics.

One notable employment of Alpha Mini robot lies in fitness and physical activity monitoring, where it has emerged as a valuable tool for promoting at-home exercise, especially in the wake of the COVID-19 pandemic. Leveraging deep learning, the robot was capable of recognizing the accuracy of physical exercises from image sequences using a custom dataset of 1,500 exercise videos. This dual functionality—combining exercise demonstration with real-time accuracy feedback—positions Alpha Mini as both a personal trainer and motivator, enabling individuals to maintain physical health effectively and safely [6].

In the realm of childhood nutrition, social robotics offers innovative solutions to tackle pressing issues like obesity and overweight. Within the HERO project, Alpha Mini has been integrated with serious games to deliver nutritional education in an engaging and persuasive manner. Acting as a personal persuasive technology, the robot motivates behavioral changes and enhances children's recall of nutritional information. A Wizard of Oz study highlighted the robot's ability to foster trust and engagement, demonstrating its effectiveness in promoting healthy dietary habits through interactive learning experiences [7].

Its initial interaction phase was conducted using the Wizard of Oz technique, meaning that all dialogues and interventions were controlled by qualified nutritionists. This ensured that all information provided to children was accurate and appropriate, eliminating potential risks related to the autonomous operation of the robot. Then, its architecture aims to personalize health interventions based on the child's user profile. The system gathers data from multiple sources, including wearable devices, smartphones, and the robot's built-in sensors, allowing it to monitor nutrition habits, mood-related behaviors, and physical activity. Additionally, HERO employs health behavior tracking through dialogue interactions, leveraging techniques from narrative medicine to encourage children to reflect on their eating habits.

The robot also integrates emotion and mood analysis, recognizing facial expressions, voice prosody, and gestures to adapt its motivational strategies accordingly [7].

By integrating these capabilities into Alpha Mini, the HERO project contributes valuable insights to the development of a shared architecture for personal robotic assistants, highlighting the necessity of personalization, emotional awareness, and ethical oversight in the design of persuasive health technologies.

Furthermore, Alpha Mini has proven effective in language learning applications. In a study with Chinese preschoolers, the robot employed social behaviors such as verbal and gestural cues to teach English vocabulary. Among these, verbal interactions were found to be the most effective in enhancing vocabulary retention, outperforming gestural and control conditions. This underscores the importance of designing robots with impactful social behaviors to maximize their educational efficacy, particularly in early childhood learning environments [8].

The use of Alpha Mini in a cooking-related English course for seniors illustrates how social robots can combine cognitive training with engaging activities to sustain participation, improve language skills, and promote mental agility. This innovative approach aligns with the growing need to address age-related cognitive disorders and encourage lifelong learning [9].

In addition to cognitive stimulation, social robots have demonstrated the potential to mitigate loneliness and social isolation, significant challenges faced by older adults that impact both mental and physical health.

Indeed, in the SISTER project, Alpha Mini was tested as a senior companion, utilizing empathy to enhance human-robot interaction. A study involving 30 older adults revealed that the empathic version of the robot, which recognized and responded to users' emotional states, provided a more positive and meaningful interaction experience. These findings emphasize the importance of designing robots capable of empathy to reduce loneliness and strengthen emotional bonds [10].

Similarly, an experimental study explored whether users perceive a social robot's ability to understand their affective states and express empathy. Two versions of a robot dialogue system were developed: a Non-Empathic Robot (NER), which interacted without considering users' emotions, and an Empathic Robot (ER), which analyzed emotional content and responded accordingly. Involving 30 participants balanced by gender, age, and empathy levels, the study demonstrated that users perceived the ER as significantly more empathic. Furthermore, a positive correlation was found between users' empathy levels and their perception of the robot's empathy. These findings suggest that a computational model of empathy in social robots should adapt to user characteristics and conversational contexts, highlighting the value of empathy in fostering meaningful human-robot interactions [10].

Proper nutrition is another essential factor for the health and well-being of older adults, especially those with cognitive impairments who are at risk of "nutritional frailty". Social robots can assist in promoting independent eating habits and delivering personalized nutritional advice. A recent prototype of a socially assistive robot integrates advanced functionalities such as recognizing eating and drinking activities, detecting and identifying food, and providing personalized recommendations through an ontology-based FoodAI service. By acting as a companion during meals, the robot aims to enhance self-care, raise food awareness, and address the unique dietary needs of older adults in nursing homes or at home, further demonstrating the transformative potential of social robotics in improving quality of life [11].

3. NAO

Recent advancements in robotics have highlighted the potential of the Aldebaran humanoid robot NAO (Figure 2) as a socially assistive robot (SAR) in various application areas, including social interactions, education, therapy, and assisted living. These applications rely on NAO's multimodal capabilities—such as motricity, functionality, and emotional engagement—which make it a valuable tool in assisting individuals, especially in socio-educational and rehabilitative contexts [12, 13, 14, 15].

One particularly promising area for the use of NAO is in therapy and education for autistic children or

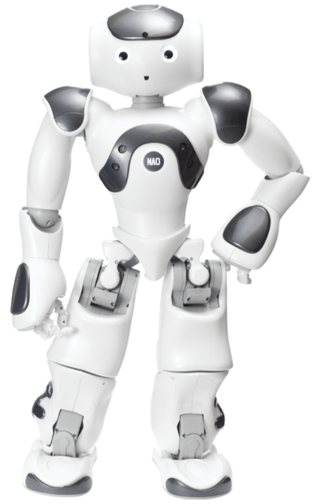

Figure 2: NAO - Aldebaran Robotics.

pediatric environments [16, 17]. Studies have demonstrated NAO's effectiveness in fostering cognitive and social skills through activities such as coordination and cooperation games designed to teach theory of mind (ToM). In these games, children interacted with either NAO or a human partner, coordinating gestures and collaborating to complete tasks. While NAO provided regular and predictable interactions, children exhibited greater progress in ToM skills after interacting with human partners, emphasizing the importance of stable motor coupling in facilitating social learning and skill transfer [18].

Then, the integration of emotional intelligence into NAO's design has expanded its applications in personalized learning and therapy. For instance, in a clothing shopping recommender system, NAO used multimodal cues such as speech body language, and facial expressions to detect user emotions and refine personalized recommendations. This approach demonstrated the robot's potential to enhance user profiling and recommendation accuracy, even in the absence of explicit feedback [19].

Moreover, studies on NAO's interactions with children during storytelling tasks have highlighted its ability to foster emotional engagement and cognitive involvement. Behavioral and psychophysiological indicators, such as heart rate and self-assessment questionnaires, revealed strong correlations between emotional states and engagement, supporting the robot's role in educational and rehabilitative settings [20].

NAO has also contributed to environmental awareness and emotional regulation by adapting to users' emotional states. In a quiz-based game designed to raise environmental awareness, NAO adjusted its responses based on detected emotions, demonstrating how socially assistive robots can leverage emotional intelligence for engaging and personalized interactions [21].

Finally, the humanoid robot NAO has been increasingly utilized as a SAR to support cognitive training interventions for patients with Mild Cognitive Impairment (MCI). Leveraging its human-like multimodal emotional expressions and body language, NAO enhances social confidence and encourages active participation in repeated cognitive exercises [22]. Research frameworks implementing SAR-based interventions, such as interactive memory training games, have demonstrated significant application value in improving therapeutic outcomes for MCI patients, including increased patient engagement and reduced depressive symptoms [23]. These interventions have been tested in ecological settings, such as Italian centers for cognitive disorders, where training sessions supported by NAO were compared with those led solely by psychologists. Results indicate that human–robot interaction reinforces treatment adherence and has led to unexpected improvements in prose memory and verbal fluency, suggesting promising potential to complement clinical practices [24].

4. Cozmo and Vector

Anki Cozmo and Vector (Figure 3) are two commercially available social robots designed by Anki for interaction and engagement. Although both robots have vehicular appearance and are not human-like, they are endowed with a set of algorithms (*emotion engine*) allowing them to accurately mimic and express emotions using an LCD screen showing animated colored eyes. Cozmo and Vector differs in their capabilities, where Cozmo is more limited and controllable only through the app, whereas Vector incorporates features such as voice recognition, command execution and environmental awareness.

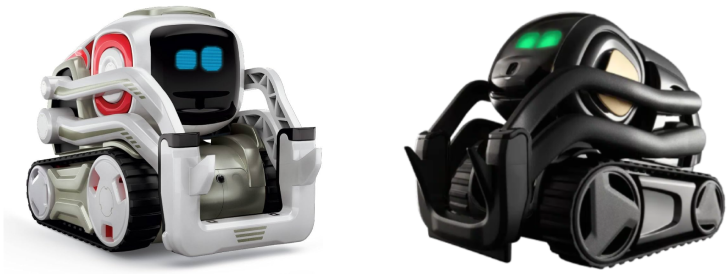

Figure 3: Cozmo (left) and Vector (right) - Anki.

Cozmo and Vector have been employed in a variety of research works, showcasing their potential for social and educational purposes. For example, in a social context, Cozmo has been used to support intellectually disabled individuals. Indeed, [25] explores the use of social robots to elicit cooperation and social interaction among autistic adults. During the study, participants played with Cozmo in small groups, resulting in high engagement, positive affect, and collaboration, particularly through Cozmo's ability to play games and interact in relatable ways.

In the educational context, [26] highlights Cozmo's utility as a companion in teaching mathematics, spelling, and other subjects to children in elementary schools through interactive games and activities. The framework includes features like computer vision, voice recognition, and the ability for teachers to customize scripts, enhancing its adaptability to different educational needs. Similarly, [27] demonstrates how Cozmo positively influenced knowledge gains among children between 14-17 years of age, especially in algebra, geometry, and trigonometry through the use of engaging material and exercises. The study showed that participants' subjective rating on their knowledge improved after the interaction, implying Cozmo potential as a non-humanoid educational tool.

Vector's ability to mimic the emotional and psychological benefits of pet ownership has been investigated in [28]. By programming the robot to express a need for daily exercise and attention, researchers observed mood improvements in participants, especially when the robot exhibited emotionally expressive behaviors.

Vector has also been integrated into health-related applications, and specifically to diet tracking. In [29], a platform for automated and unobtrusive system for diet tracking is presented. The system utilizes Vector to autonomously capture food photos, motivate children, and analyze dietary habits using deep learning through a REST microservice architecture. However, the study does not provide an evaluation of the platform in real-word scenarios.

Finally, during the COVID-19 pandemic, Vector's adaptability was further explored designing and developing VectorConnect [30], a robot teleoperation system to facilitate physical play and social interaction for children experiencing social distancing allowing two remote users to communicate while playing with a Vector robot. The VectorConnect platform was distributed free of charge and used by hundreds of people between June and September 2020.

5. PARO

PARO (Figure 4) is a robotic baby seal developed by AIST to provide emotional support and calming effects, similar to animal-assisted therapy. It is equipped with touch, sound, vision, motion, and temperature sensors to recognize whether it is being held. Furthermore, it can express emotions through movements of its head, flippers, and eyes.

Figure 4: PARO - AIST.

Several studies have highlighted its potential to enhance psychosocial well-being and reduce negative symptoms in older adults, particularly those with dementia. For instance, [31] shows a significant reduction in loneliness among residents of a care facility in New Zealand who interacted with PARO. In addition, during the study, participants engaged more actively with the robot than with the resident dog. Similarly, [32] shows how PARO interventions can improve quality of care and quality of life for dementia patients, emphasizing its role as a supportive tool for caregivers.

This robot has also shown effectiveness in reducing symptoms of agitation and depression. In [33], residents of ten nursing homes in Norway, who participated in PARO-assisted group activities over 12 weeks, experienced significant declines in these symptoms compared to a control group. The study concluded that PARO is a suitable nonpharmacological intervention for neuropsychiatric symptoms. Likewise, [34] demonstrated increased positive affect and decreased negative behaviors among veteran residents using the robot in a Veterans Affairs care facility over the course of nearly a year and a half, suggesting its utility for managing mood and behavioral issues in dementia care.

In addition to its applications in elderly care, PARO has also been used as a therapeutic tool for autistic and neurodivergent children, helping them improve social interaction and emotional engagement. For example, [35] evidenced PARO's efficacy in improving communication and social skills in autistic children without Intellectual Impairment. By acting as a social mediator, PARO facilitated interactions with adults, showing a positive correlation in social engagement during therapeutic sessions. Further evidence of the effectiveness in ASD therapy is provided in [36], which observed that the robot could improve communication and reduce impulsive behaviors or anxiety in some patients. However, the study also noted that certain children found PARO's physical features, such as its large eyes or slight mechanical noise, off-putting.

In the context of managing emotional responses, the influence of PARO on mood, anxiety and arousal has been investigated in children between the ages of 6 and 9, following exposure to stressful tasks [37]. Participants who interacted with the robot showed an increase in positive mood than children in the control groups. However, no differences where found in terms of negative mood, anxiety or arousal. Instead, [38] showed how the robot helped in reducing pain and anxiety in pediatric patients. The study noted that robot-assisted therapy was particularly impactful when parents participated alongside their children, fostering empathy and improving coping mechanisms.

6. Conclusions and future works

From the analysis of the literature and research projects involving the personal robots we examined (Alpha Mini, NAO, Cozmo, Vector, and PARO), several key characteristics emerged, particularly regarding natural interaction, adaptability, and user-friendly design. Significant advancements in the field have been highlighted. In addition, this paper underscores the importance of focusing on these fields for vulnerable populations, such as children, older adults, autistic people, and disabled individuals. Robots designed with cognitive architecture are capable of aiding and supporting stronger social and cultural integration and thus are powerful means of improving emotional well-being and feeling of belonging in the community. The software architectures and applications of these personal or domestic robots revealed their remarkable versatility and the wide range of applications available in the field of social assistive robots and companion robots. The literature analysis also provided insights into the contexts in which personal robots can be effectively utilized. Despite the diversity of applications, software architectures, and the variety of contexts in which personal robots are employed, we believe it is essential to develop a general software architecture for personal robots. Such architecture should enable interaction with people across different contexts, purposes, and applications. With the pervasive integration of large language models (LLMs) into daily life, it is crucial to incorporate these technologies into next-generation architectures, augmented by the sensors and actuators of personal social robots.

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