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Research Article

Artificial Intelligence-Powered Robotic Technology for Transforming Palliative Care

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ABSTRACT

Palliative care seeks to improve the quality of life of patients with life-threatening illnesses by addressing their physical, emotional, and psychological needs. However, global challenges such as workforce shortages, limited access to specialized care, and inconsistent care quality demand innovative solutions. Advances in artificial intelligence (AI)-powered robotics offer transformative potential to overcome these barriers and strengthen palliative care delivery. This study explores how AI-driven robotic technologies support palliative care through applications in symptom monitoring, clinical decision-making, emotional companionship, and personalized care planning. It reviews cutting-edge robotic systems, including assistive, companion, diagnostic, nursing, procedural, service, and rehabilitation robots. Enabled by machine learning, deep learning, natural language processing, and computer vision breakthroughs, these systems help monitor vital signs, manage symptoms, plan end-of-life care, deliver medication, alleviate pain, and support mobility through robotic exoskeletons. They also assist patients with daily activities and offer respite to caregivers. Despite their promise, AI-powered robotics face significant challenges, including ethical concerns, algorithmic bias, data privacy risks, cultural resistance, and resource limitations. When integrated ethically and thoughtfully, AI-powered robotics can extend the reach of palliative services, support human caregivers, and enhance outcomes for patients and families. Collaboration among healthcare professionals, AI researchers, engineers, and policymakers is crucial to ensure that robotic technologies remain patient-centered, safe, and accessible. By merging technological innovation with compassionate care, AI and robotics can redefine the future of palliative care globally.

1. INTRODUCTION

The rising burden of both communicable and non-communicable diseases in low- and middle-income countries (LMICs) has led to increasing morbidity and mortality rates, particularly among younger populations. This trend undermines productivity and perpetuates cycles of poverty and suffering. Limited health insurance coverage and high out-of-pocket expenses prevent many individuals from accessing treatment for otherwise curable conditions. Palliative care addresses these systemic gaps by improving the quality of life (QoL) for patients and families through physical, psychological, social, and spiritual support [1][2]. Researchers such as Rahman et al. [2], Mosha and Ngulube [3], Zhang et al. [4], and Allcroft et al. [5] describe palliative care as a holistic, interdisciplinary approach that manages pain and distress in patients with serious illnesses. Gonçalves and Caramelo [6] emphasize enhancing the QoL, alleviating symptoms, facilitating decision-making, and supporting caregivers. Palliative care, which can be incorporated at any point throughout a patient's illness, guarantees comfort and dignity for patients suffering from heart failure, dementia, cancer, and other chronic diseases while also assisting curative treatments.

Despite its proven benefits, palliative care remains inaccessible to most of the global population. According to the World Health Organization (WHO), only 14% of the 56.8 million people in need each year—25.7 million of whom are in their final year of life—receive palliative care services [2][7][8]. By 2025, demand is expected to rise to 73.5 million annually, a 74% increase over three decades. LMICs will face the most significant challenges, with 80% of the global need and an 83% surge in demand—nearly double that of high-income countries. This growth stems from rising populations and increased chronic

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conditions requiring palliative interventions [9]. Palliative care teams manage symptoms such as pain, fatigue, breathlessness, and nausea while providing psychological, spiritual, and social support. Effective communication helps patients understand their condition, weigh treatment options, and make choices aligned with their values. Coordinated care across hospitals, clinics, and homes ensures continuity and comprehensive support throughout the illness trajectory [3][10][11].

Palliative care emphasizes a patient-centered, interdisciplinary model. Physicians, nurses, social workers, and chaplains work together to address patients' holistic needs. Early integration—from diagnosis through treatment—enables timely interventions and shared decision-making. Primary care providers, including acute care surgeons, often deliver basic palliative services, while specialists manage complex cases [5][11]. Effective care involves assessing physical, emotional, spiritual, and social needs, respecting patient autonomy, and identifying concerns early to improve outcomes [7]. Once limited to end-of-life support, palliative care encompasses symptom control, psychological assistance, communication, and caregiver support [10]. It aims to relieve respiratory symptoms, pain, fatigue, and emotional distress while addressing overlooked issues like skin conditions that affect QoL [12–14]. End-of-life care ensures patients' wishes are respected and that compassionate support is provided [15]. As healthcare systems increasingly recognize its value, palliative care has become integrated into broader health programs [16–25]. Nurses play a pivotal role in assessment, symptom management, and coordination, helping to reduce unplanned hospitalizations, depression, and financial strain. However, access remains uneven, especially in rural and underserved areas, due to poor infrastructure, inadequate training, lack of policies, labor shortages, and persistent misconceptions [16][26]. Financial and communication barriers further hinder timely and appropriate care [27]. AI-powered robots provide powerful opportunities to enhance palliative care. These devices support symptom management, patient monitoring, and emotional well-being. AI chatbots educate patients and assist with symptom tracking, while decision-support systems aid with end-of-life planning. Advanced monitoring systems assess vital signs and deliver pain relief. Companion robots provide social interaction and therapeutic engagement, while robotic assistants aid with daily tasks and remote consultations. Predictive models support personalized decision-making [28-33].

As demand for palliative services grows, AI-driven robotic technologies present innovative ways to complement traditional care [25][34]. They are particularly effective in managing chronic illnesses and alleviating pain [35-37]. These systems incorporate machine learning (ML), deep learning (DL), natural language processing (NLP), and computer vision (CV) to support patients with severe or terminal conditions. Core components include AI algorithms, sensors, motion control, and cloud-based systems [38]. Robotic technologies include assistive, companion, diagnostic, procedural, and rehabilitation robots [31][39]. Real-world examples include PARO, Robear, ElliQ, Lio, Jibo, Mabu, Mylo, Care-o-bot, and IBM Watson for Oncology [40]. These robots improve efficiency, reduce operational costs, and enhance safety in hazardous tasks. Their precision, adaptability, and cost-effectiveness make them valuable additions to palliative care teams [32][38]. Despite these benefits, implementation faces challenges. Concerns about data privacy, algorithmic bias, and cultural resistance persist. Ethical and legal issues, along with technical complexity and regulatory barriers, complicate adoption [32][33][41-45]. Ensuring equitable access, effective regulation, and ethical integration remains essential to harnessing AI's full potential in palliative care.

Recent research has highlighted the potential of AI-powered robotic technology in transforming palliative care. Pinto et al. [25] reviewed the use of AI in palliative care communication, while Bressler et al. [46] utilized AI/ML models to identify potential beneficiaries for palliative care. Wilson et al. [47] studied the impact of an AI decision support tool on palliative care referrals for hospitalized patients. Feng et al. [48] explored AI and robotics in palliative care. Nonetheless, no studies have focused on exploring the application of AI-powered robotic technology in transforming palliative care. This study addresses this gap by providing an overview of how these technologies can work together.

This study makes several significant contributions.

- It describes the evolution of palliative care, core concepts of AI and robotics technology, and the application of AI and robotics technology in transforming palliative care.
- It explores AI-powered robots in palliative care, different types of AI-powered robots, and their applications in improving patient care.
- It highlights real-world examples and case studies demonstrating how AI-powered robots transform palliative care.
- It identifies the challenges and limitations of using AI-powered robots in transforming palliative care.
- It proposes future research directions for advancing AI-powered robotics in palliative care.

The manuscript is organized as follows: Section 2 provides the study's background by exploring the evolution of palliative care, key AI concepts, AI applications in palliative care, fundamental robotics technology principles, and the role of robotics in palliative care. Section 3 presents AI-powered robots in palliative care, detailing their types and applications. It also highlights real-world examples and case studies that showcase how AI-driven robotics enhances patient care and supports healthcare providers. Section 4 describes the challenges encountered by AI-powered robots in palliative care. Section 5 examines future research directions for AI-powered robotic technology in transforming palliative care. Finally, Section 6 presents the conclusion of the study.

2. BACKGROUND

2.1 Evolution of Palliative Care

The WHO defines palliative care as a strategy that helps patients and their families deal with the challenges of a life-threatening illness by preventing and alleviating suffering through early detection, precise assessment, and treatment of pain and other physical, psychological, and spiritual issues [8][10][24][49][50]. It emphasized palliative care as a fundamental human right and a part of primary and integrated healthcare; both aim to reduce the patient's suffering and symptoms [24]. Palliative care emerged from the modern hospice movement of the 1960s, pioneered by Dame Cicely Saunders. In 1967, she established St. Christopher's Hospice in London, where she developed an interdisciplinary model to support patients nearing the end of life. By introducing a multidisciplinary approach, Saunders challenged the prevailing belief that a lack of a cure signified a physician's failure and significantly improved end-of-life care. Her work gained international recognition, inspiring clinicians such as Canadian urologist Dr. Balfour Mount. After visiting St. Christopher's in 1973, Dr. Mount established a hospice-style inpatient unit at the Royal Victoria Hospital in Montreal. Because the term "hospice" carried negative connotations in French, he coined the term "palliative care," derived from the Latin "palliare," meaning "to cloak" [51].

A specially trained team of doctors, nurses, and specialists can provide palliative care alongside a patient's primary treating team, offering an extra support layer. With or without direct assistance from specialized palliative medicine doctors, primary healthcare providers—such as family doctors, general practitioners, and nurses—can offer basic palliative care in homes, residential aged care institutions, or community settings. Primary palliative care patients may have predictable, intermediate, or variable demands. In contrast, specialist palliative care focuses on managing refractory pain, addressing complex symptoms, and handling almost hopeless circumstances. Palliative care experts and primary care physicians work together in secondary palliative care through consultation liaisons or shared care models [5]. Palliative care addresses psychological and emotional disorders like anxiety and hopelessness as well as physical discomforts, including pain, nausea, exhaustion, and breathing problems to manage symptoms. A holistic approach considers patients' emotional, social, and spiritual requirements while acknowledging them as whole individuals. The primary goal is to enhance the patient's QoL by minimizing suffering and ensuring comfort, whether done with curative treatments or in situations where curative options are no longer effective.

Furthermore, palliative care encourages candid dialogue and assists patients and their families in deciding on end-of-life care and life-sustaining treatments consistent with their values and goals. Palliative care is adaptable enough to accommodate patients' needs in various locations and is provided in hospitals, nursing homes, outpatient clinics, and homes. It also helps families cope with caregiving, grief, and loss stress by offering them respite care, counseling, and assistance. As a patient's disease progresses, palliative care may give way to hospice care, which ensures the patient's comfort, dignity, and emotional and spiritual support in their final days. Because they provide palliative care services, they are essential to the healthcare system. These individuals frequently experience incapacitating symptoms such as nausea, vomiting, discomfort, respiratory issues, and open wounds. To ensure their well-being, healthcare systems must provide palliative care 24/7, regardless of a patient's location, financial situation, or other conditions. Patients' QoL is improved, their families are supported, and dignified end-of-life care is guaranteed when these services are made immediately available [24]. All tiers of the current healthcare system should incorporate efficient palliative care services, focusing on community-based and home-based care. The public and private sectors must work together while adjusting to society's cultural, social, and economic circumstances.

Palliative care must be strategically linked to adult and pediatric preventive, early detection, and treatment programs to satisfy community needs and maximize scarce resources. In addition to infectious diseases like HIV/AIDS, severe trauma, and neurological disorders, it is essential in the management of several life-threatening illnesses, including non-communicable conditions like cancer, cardiovascular disease, and chronic respiratory diseases [52]. Some of palliative care's main advantages are increased symptom management, high patient and family satisfaction, increased communication, and possibly more prolonged survival. Research shows that patients receiving palliative care are more comfortable and have better symptom management. Because palliative therapies address medical demands and emotional and psychological well-being, families and patients frequently express greater satisfaction. Moreover, palliative care teams facilitate open and honest communication among patients, families, and doctors, enabling informed decision-making. Some research suggests that integrating palliative care with curative treatments may extend survival by reducing distress and improving overall symptom control.

2.2 Core Concepts of Robotics Technology

Robotic technologies have transformed numerous industries, including healthcare, by increasing efficiency and minimizing the need for direct human contact. As the need for palliative care increases, the integration of robotics has significantly advanced in the field. These machines, designed to perform tasks autonomously or with minimal human input by mimicking human intelligence, exemplify the capabilities of modern robotics [53][54]. The field of robotics draws on multiple disciplines—mechanical engineering, electrical engineering, computer science, AI, and control systems—to design, build, and operate intelligent machines. The words robot and robotics have surprisingly complex origins and meanings. The term robot derives from the Slavic word “robot,” which means servitude, servant, or, more disturbingly, slave. Czech writer Karel Čapek first introduced the word in print in his 1920 play R.U.R. (Rossum’s Universal Robots), depicting a factory manufacturing androids. Later, in 1941, Isaac Asimov coined the term robotics in his short story “Liar!” Since then, robots have evolved to describe various machines or devices that perform human tasks autonomously or through computer control [55].

Several essential elements comprise robotics technology, which permits intelligent and self-governing behavior. The mechanical structure, which consists of the robot's frame, joints, limbs, and actuators, forms its physical framework and often mimics human or animal movement; however, its design may change based on its function. Sensors such as cameras, gyroscopes, accelerometers, proximity, and temperature sensors enable the robot to perceive its surroundings instantly and collect data. Actuators convert energy into mechanical motion, allowing the robot to move and interact with objects. Pneumatic systems, hydraulic cylinders, and electric motors are a few actuators. The hardware and software control system interprets sensor data, runs AI models or preprogrammed algorithms, and controls the actuators. Robots can make decisions independently, adjust to changing conditions, and improve their performance over time with the help of AI and ML. Thanks to these technologies, robots can learn from data, identify trends, and continuously improve their behavior based on feedback. Furthermore, more intuitive and natural communication between humans and robots is made possible by developments in human-robot interaction technology, such as voice recognition, gesture control, and emotional response systems. Ultimately, these technologies enhance user experience and collaboration by facilitating familiar and responsive interactions between humans and robots [54].

The global robotics market, valued at US$71.2 billion in 2024, is expected to reach US$108.43 billion by 2025, fueled by increasing investments and expanding applications. The medical robotics market continues to gain momentum within this sector and is projected to grow to US$12.7 billion by 2025, highlighting its expanding role in healthcare [56][57]. Palliative care has tremendously benefited from advances in robotic technology, which have raised the QoL for patients with severe or fatal illnesses. These technologies aim to support patients and healthcare providers by addressing end-of-life care's psychological, emotional, and physical challenges. Robots assist healthcare workers in providing care more efficiently, precisely, and empathetically by assisting with tasks, including physical care and emotional and social engagement.

Robotic technology has many uses in palliative care, including increasing patient autonomy, improving care delivery, and fostering mental health. Assistive robots preserve patients' dignity and relieve caregiver stress by helping them with daily tasks such as eating, dressing, and getting around. People who are lonely or depressed, especially those who are alone, benefit from the communication and emotional support that social and companion robots offer. By facilitating remote communication with family members and medical experts, telepresence robots help to maintain social bonds. While rehabilitation robots improve physical performance through strength training and mobility exercises, medication delivery robots provide accurate and timely doses. Robots with sensors enable medical professionals to keep an eye on feelings like pain and worry so they can successfully modify treatment plans. Exoskeletons and lifts are examples of physical care robots that assist with movement and repositioning and lessen the physical strain on caregivers. Furthermore, integrated health monitoring systems help in managing intricate prescription schedules and vital sign tracking to enhance adherence and lower errors, while robotic companions offer social connection and cognitive stimulation.

Robotic technology provides several significant advantages in palliative care by improving patient well-being and assisting caregivers. By facilitating mobility, lowering pain, and encouraging social interaction, these technologies help patients maintain their independence and dignity while enhancing their QoL. For example, robotic exoskeletons enable individuals with spinal cord injuries to stand and walk, leading to psychological and physical benefits. Robots also relieve the mental and physical strain on caretakers by doing duties like lifting, moving, and keeping an eye on patients, freeing them up to concentrate more on providing emotional support. Robotic companions promote emotional health, cognitive stimulation, and communication through discussion and mental activities—particularly in individuals experiencing cognitive loss. Furthermore, robotic systems improve treatment precision and overall care management by controlling intricate drug schedules, modifying dosages, and guaranteeing on-time delivery [58][59].

2.2.1. Application of Robotics Technology in Palliative Care

This section provides an in-depth examination of how robotic systems are being integrated into palliative care settings.

- ***Emotional support through social robots***

Social robots integrate advanced technologies and patient-specific applications to provide emotional support [60]. Robots like Paro enhance patient well-being by offering companionship and reducing loneliness, especially among individuals with cognitive impairments. These technologies can also support healthcare workers by delivering interactive breaks, monitoring emotional states, recommending mental health interventions, reducing stress, and improving overall resilience. By fostering effective human-robot collaboration, these systems boost workplace efficiency and promote well-being in high-pressure environments [61]. This cross-disciplinary innovation underscores how robotics and advanced computing transform care delivery and operational practices across various sectors.

- ***Robots for physical assistance and mobility***

Robots significantly support palliative care by assisting with physically demanding tasks such as lifting, repositioning, and transferring patients, reducing patient discomfort and easing the physical burden on caregivers. Advanced robotic systems—including exoskeletons and assistive devices like Robear—perform these tasks precisely and safely, minimizing the risk of injury for patients and staff [62]. These technologies also promote patient autonomy by enabling greater mobility and engagement in daily activities, helping preserve dignity, and improving QoL. Innovations like the ReWalk exoskeleton, initially developed for rehabilitation, have found meaningful applications in palliative care by allowing individuals with limited mobility from neurological conditions to stand and walk, thus supporting independence during the final stages of life [63].

- ***Smart sensor technologies for continuous monitoring***

Robotic systems with advanced sensor technologies transform palliative care by continuously and non-invasively monitoring vital signs and other key health metrics. These systems track real-time data such as heart rate, respiratory rate, and body temperature, offering critical insights into a patient's condition without disturbing their rest. Caregivers can concentrate more on meaningful, one-on-one patient contact by reducing the need for frequent manual inspections [64]. Additionally, these innovative technologies promptly detect abnormalities and issue early alerts, enabling timely interventions that help prevent complications and improve patient outcomes [27].

- ***Palliative care education and simulation***

Robots are increasingly vital in healthcare education as they train providers in palliative care through realistic simulations. Robotic simulators replicate patient symptoms and responses, allowing caregivers to practice managing complex, emotionally charged end-of-life scenarios. These hands-on simulations enhance caregiver readiness by enabling them to navigate ethical dilemmas, emotional stress, and clinical challenges in a safe, controlled environment [65]. By engaging directly with these scenarios, healthcare professionals build competence and confidence, improving their ability to communicate with patients and families, make critical decisions, and provide compassionate care. This form of experiential learning has proven effective in raising the quality of palliative care across diverse healthcare settings.

- ***Robotic assistance for caregiver support***

Robots like Care-O-bot and Robear increasingly support caregivers by handling physically demanding tasks such as lifting, repositioning, and feeding patients. These robotic systems reduce caregiver strain, lower the risk of burnout and injury, and enhance the quality of care [66]. In hospice and home care settings, they improve patients' and caregivers' safety and well-being, creating a more sustainable caregiving environment. Robots help patients and their support teams live better lives by relieving physical strains, allowing caregivers to concentrate on giving more compassionate and attentive care [62].

- ***Robotics for hospice and end-of-life care***

Robots enhance patient comfort and well-being in hospice and end-of-life care by assisting with daily tasks such as feeding, medication reminders, and social interaction. For instance, the Jibo robot engages patients in conversation and cognitive activities, helping reduce emotional distress for patients and their families. By offering companionship and promoting cognitive stimulation, Jibo supports patients facing cognitive decline and fosters a greater sense of autonomy [67]. These robotic systems also ease the emotional burden on caregivers and family members while promoting connection, which improves the patient's overall QoL. Research further shows that such robots can alleviate loneliness and boost social interaction [68].

- ***Robotic technologies for symptom monitoring***

These days, sophisticated AI and sensor-equipped robots are essential to palliative care since they continuously monitor symptoms, including vital signs and emotional states. They constantly track heart rate, blood pressure, and respiration, enabling early detection of changes in a patient's condition [69][70]. These systems prove especially valuable when patients are too frail to self-report or unable to communicate effectively. By predicting potential adverse events, the robots help caregivers deliver proactive care, minimize complications, and improve patient outcomes. Their ability to support timely interventions is vital in palliative care, where effective symptom and discomfort management directly enhances the QoL [64].

- ***Telepresence robots for remote family interaction***

Telepresence robots, like those developed by Double Robotics, strengthen connections between patients and their families by enabling virtual interaction during critical moments. These robots help reduce feelings of isolation by allowing loved ones to offer emotional support even from a distance. When in-person visits are not feasible, they also provide remote monitoring by medical professionals, guaranteeing that patients receive thorough and consistent care [42]. This technology maintains QoL in palliative care settings, where emotional support and ongoing monitoring are essential. By providing real-time video and communication, telepresence robots meet patients' emotional and clinical needs, regardless of physical location [71].

- ***Robotic exoskeletons for mobility***

Robotic exoskeletons, such as the ReWalk system, support patients with physical limitations in palliative care by enabling mobility and promoting psychological well-being. These devices help terminally ill patients walk and perform daily activities, allowing them greater independence [72]. Beyond improving physical function, exoskeletons enhance patients' autonomy, reduce feelings of helplessness, and provide emotional uplift by empowering them to engage more fully in everyday life. By fostering physical and emotional resilience, these technologies significantly improve overall quality of life [73].

- ***Robots for psychological and cognitive support***

Robots designed for psychological support engage patients through interactive games, cognitive tasks, and conversation to help alleviate depression and anxiety. In settings with limited human resources, robots like Pepper and Jibo provide essential mental stimulation and distraction therapy, effectively addressing symptoms of emotional distress and cognitive decline [64][68]. These robots engage patients in meaningful activities, stimulate memory, and promote emotional resilience by offering companionship and reducing isolation—a common challenge in palliative care. Improving mood, supporting mental health, and encouraging positive interactions enhance emotional well-being and quality of life. Studies have demonstrated that Jibo helps enhance the mental health of senior patients by conversing with them, entertaining them, and reminding them to take their meds or engage in certain activities [71].

- ***Robotic companions and social interaction***

Social isolation is a significant concern for palliative care patients due to limited human interaction. Robotic companions, particularly social robots, help alleviate loneliness by offering emotional support, interaction, and comfort. For instance, the "PARO" robot, designed as a baby seal, has been effectively used in palliative care to provide emotional comfort to patients with dementia or other cognitive impairments. By responding to touch and voice, PARO offers companionship, reduces anxiety, and improves patients' emotional well-being in hospice care.

- ***Robotic surgery and minimally invasive procedures***

In palliative care, surgical interventions may be necessary to relieve symptoms like pain or obstruction. Robotic surgery provides greater precision, reduces risks, and promotes faster recovery compared to traditional methods, which is especially important for terminally ill patients with compromised health. For instance, patients with severe cancer or other life-limiting illnesses can have less invasive procedures, thanks to the da Vinci Surgical System. The precision of robotic-assisted surgery minimizes damage to surrounding tissues, making it particularly beneficial for palliative care patients in frail health [74].

- ***Robotic medication management***

Robotic technology enhances medication management in palliative care by ensuring that patients receive the correct dosages at the right times. These robots can monitor patient conditions and adjust drug delivery as needed, reducing human error and improving comfort. For example, Aethon's "TUG" robot system is used to transport medications and medical supplies in healthcare settings. In palliative care, these robots ensure the timely delivery of drugs, minimizing delays and reducing the workload on healthcare workers, allowing them to focus more on direct patient care [75].

- ***Robotic telepresence for remote care***

In palliative care, telepresence robots are becoming increasingly valuable, predominantly for patients who cannot leave their homes or hospices. These robots enable healthcare professionals to monitor and interact with patients remotely, offering essential care and emotional support without being physically present. For instance, the "Double Robotics" telepresence robot allows healthcare providers to assess patients' conditions remotely, communicate with them, and even speak with their families. This technology is invaluable when family members cannot be present in person or in remote places [76]. Fig. 1 summarizes the application of robotics technology in palliative care.

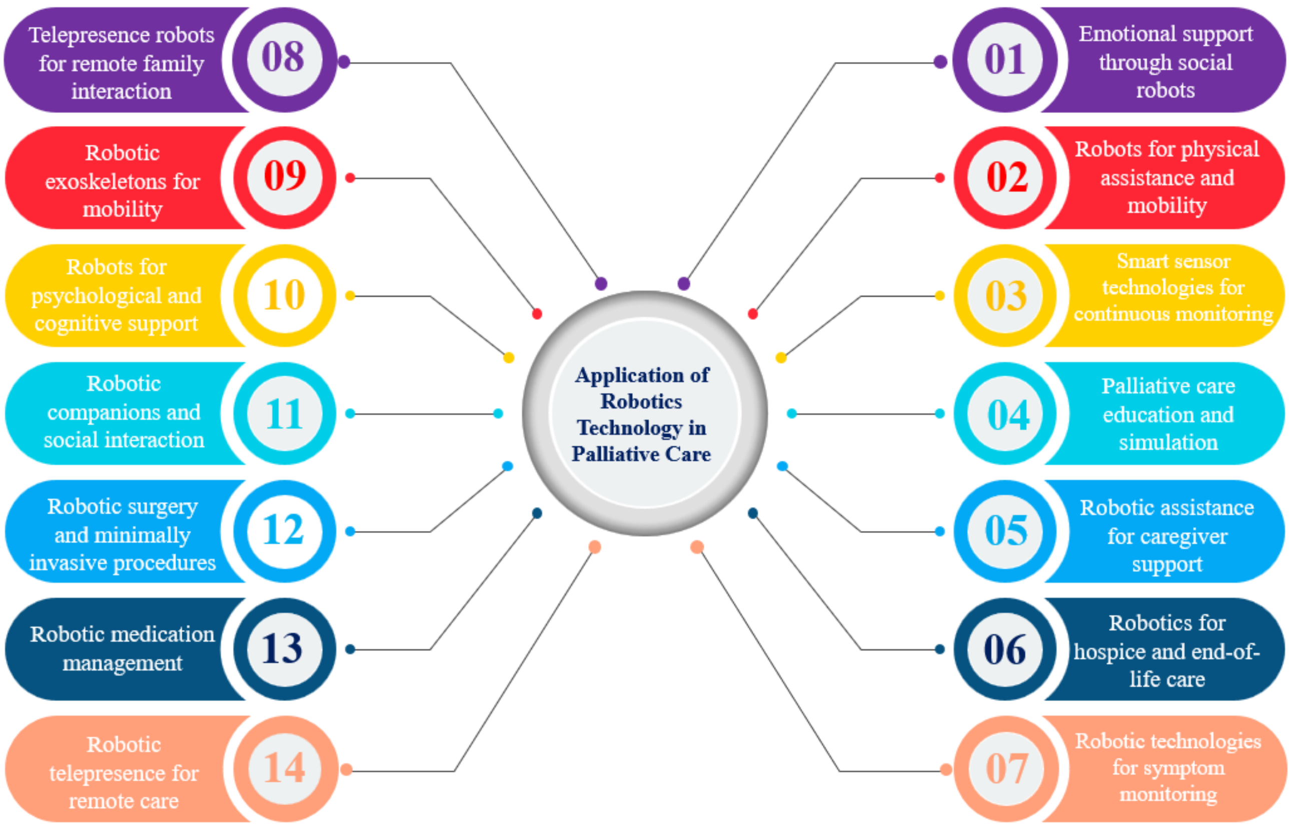

Fig. 1. Summary of the application of robotics technology in palliative care.

2.3 Core Concepts of Artificial Intelligence

In recent years, AI has transformed palliative care by improving patient outcomes, enhancing the quality of care, and streamlining resource management across the healthcare field. AI focuses on developing intelligent machines and robots that can autonomously solve cognitive tasks traditionally associated with human intelligence. These tasks include learning, logical reasoning, problem-solving, image and speech recognition, perception, decision-making, natural language understanding, and pattern recognition [53][77-79]. AI systems use sensors to perceive their environment with minimal human intervention and rely on computational models, algorithms, mathematical formulas, and rule-based methods that replicate intelligent behavior inspired by the human brain [44][55][78][80][81]. Intelligent systems interact with their environment, process information, and make autonomous or semi-autonomous decisions to serve societal needs. By learning directly from large datasets, these systems can conclude independently and adapt to new information without explicit programming for each task. The goal is to replicate human cognitive abilities through data-driven approaches. Advances in computational power, technology, and research have facilitated the integration of AI into robotic systems [79].

The AI healthcare market is rapidly expanding and is projected to reach US$24.18 billion by 2025, driven by increased funding and the widespread adoption of AI technologies across the sector. Simultaneously, the long-term care market—including palliative care services—is expected to grow by US$394.8 billion between 2024 and 2028. This growth stems primarily from a rising aging population and the growing impact of AI on healthcare trends. With powerful data analytics capabilities, AI can rapidly and accurately analyze vast amounts of structured and unstructured electronic healthcare data. Machine learning, DL, NLP, CV, and robotics support symptom management, prognostication, clinical decision-making, communication, and resource allocation [78][82]. AI-driven models outperform traditional tools in predicting short- and long-term mortality using data from electronic health records (EHRs), imaging, and clinical narratives, facilitating timely goals-of-care discussions and advance care planning. NLP tools extract relevant information from clinical notes to identify palliative care needs and track symptom burden. Moreover, AI enhances communication and workflow through chatbots and virtual agents offering psychosocial support, education, and triage for non-urgent concerns. Predictive algorithms help clinicians identify high-risk patients, prioritize care, and tailor interventions. By standardizing assessments and expanding access to expert care, AI also promises to reduce disparities in underserved populations. Fig. 2 illustrates an overview of AI techniques, such as ML, DL, NLP, and CV, and their applications in palliative care.

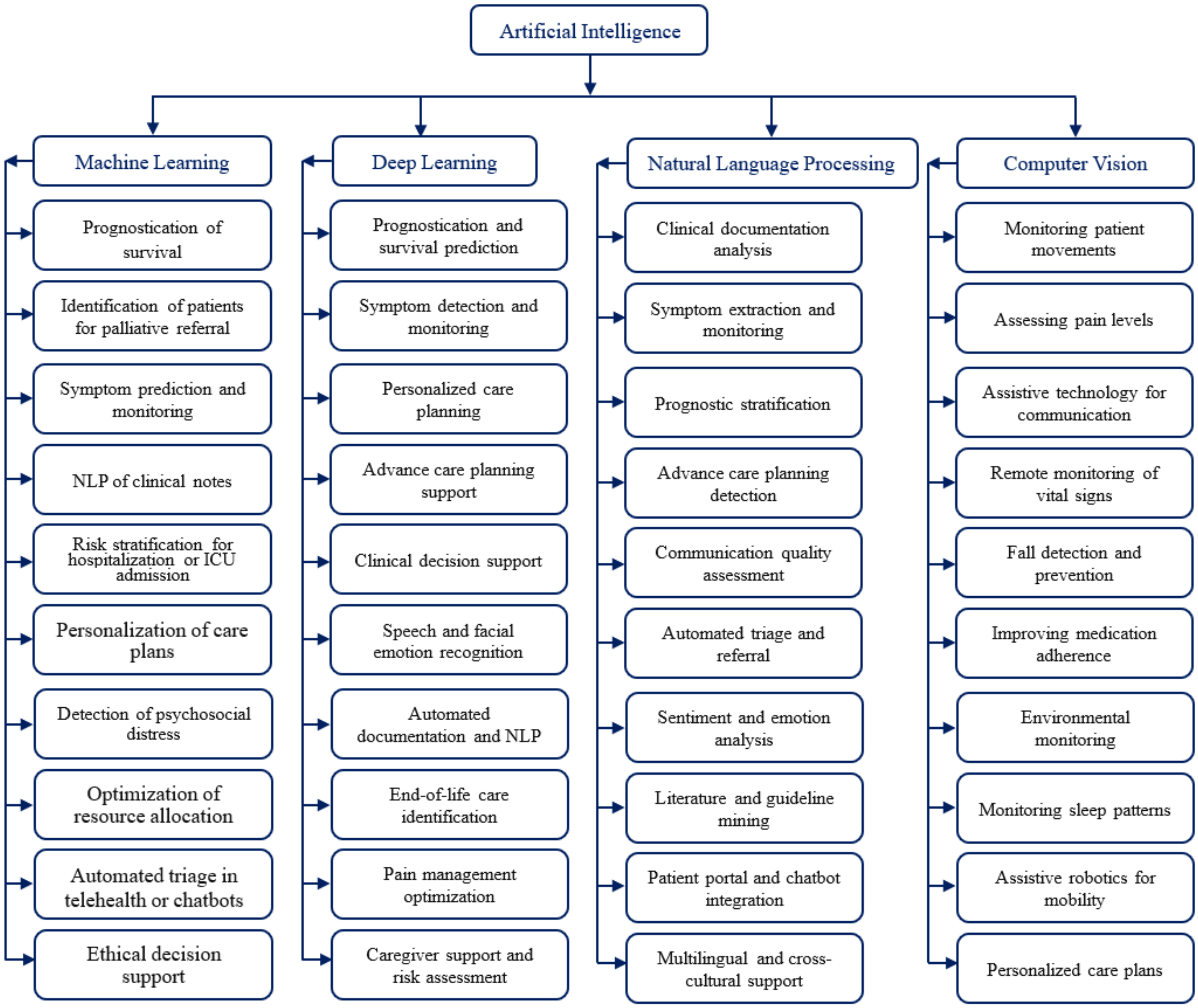

Fig. 2. Illustrates an overview of AI techniques and their applications in palliative care.

2.3.1. Machine Learning

ML analyzes data, finds patterns, makes predictions, and aids decision-making using statistical models and algorithms based on prior experiences. It enables computer systems to learn from data and enhance performance on particular tasks without explicit programming. ML algorithms look for patterns and relationships in big datasets to carry out functions like classification, regression, clustering, and optimization. They mimic elements of human intelligence through ongoing learning and adaptability [77–80][83]. ML systems can find new patterns and produce insightful conclusions using various predictive approaches, such as image recognition, NLP, recommendation systems, and medical data analysis. These methods use training data to create mathematical models that can independently predict outcomes or make decisions. The algorithms employ the patterns and correlations they find in the massive volumes of data they analyze to build models that can be applied to new, untested data. This process powers predictive analytics, increasing forecast accuracy [78][84]. ML systems use mathematical optimization techniques, computational statistics, and data mining to improve their performance over time. They automate processes that people have historically done and improve predicted accuracy as they process more data.

Different approaches to addressing complicated issues are provided by the four primary categories of ML: supervised, unsupervised, semi-supervised, and reinforcement learning [83]. While unsupervised learning uses methods like clustering to find hidden patterns and relationships in unlabeled data, supervised learning uses labeled datasets to train algorithms for regression and classification tasks. Labeled and unlabeled data are combined in semi-supervised learning to enhance model performance, particularly when unlabeled data is plentiful, and labeled data is scarce. This strategy uses graph-based methods, generative models, entropy minimization, and semi-supervised support vector machines. Through interaction with its surroundings, an agent learns from feedback to gradually improve behavior via reinforcement learning [53][78][85]. By finding patterns in training data, ML systems continuously improve their models, enabling them to perform jobs more accurately and effectively [86]. Machine learning models gradually increase their predictive power by analyzing examples from training data and adding expert observations. As these systems process more data, their accuracy improves, and human functions can be automated more successfully. ML applications are found in various domains, including robots, autonomous cars, recommendation systems, image and audio recognition, and NLP [79][86]. These technologies allow machines to recognize new patterns and predict their behavior.

By evaluating vast amounts of patient data, ML greatly improves clinical decision-making in palliative care and leads to better results. It makes it possible to precisely forecast survival, identify patients who benefit from early palliative treatment, and accurately predict and monitor symptoms. ML personalizes care plans and evaluates the risk of hospitalization or intensive care unit admission. It also interfaces with chatbots and telemedicine services to automate triage, identify psychosocial distress, and maximize resource allocation. ML assists in making moral decisions, customizes treatment regimens, schedules interventions correctly, recognizes patterns, and predicts how a disease will develop. It also supports more responsive, high-quality care in palliative situations by assisting practitioners in anticipating patient requirements.

2.3.2. Deep Learning

Deep learning, a subset of ML, employs multi-layered artificial neural networks (ANN) to perform complex tasks. These networks interpret intricate inputs—such as voice, images, and text—using supervised, unsupervised, and reinforcement learning techniques [53][78]. Inspired by the human brain's architecture, DL algorithms replicate neural networks composed of interconnected nodes, or neurons, that analyze data, detect complex patterns, and generate predictions [83][86]. ANN processes information in a way that mirrors biological neurons. Most networks have three primary layers: input, hidden, and output. The input layer receives raw data, with each node representing a specific feature or independent variable. This data passes through hidden layers—the network's core—where learning and data processing occur. These layers are connected by weighted links, and nonlinear activation functions such as ReLU, Sigmoid, and Tanh enable the network to learn complex patterns. The number of hidden layers and neurons influences the model's learning capacity; while more layers can enhance performance, they also increase the risk of overfitting. The output layer delivers the final result. Regression tasks typically contain a single neuron that outputs a numerical value; in classification tasks, each class is assigned a neuron [83][86][87].

Convolutional neural networks (CNNs), specialized ANN, represent a core technique within DL. CNNs have transformed medical diagnosis, image recognition, NLP, machine translation, and audio recognition by enabling models to learn hierarchical data representations. DL excels at managing large volumes of unstructured data, making it particularly effective in addressing challenges related to partial detectability and limited feature accessibility [53][78][79]. In the context of palliative care, DL significantly enhances clinical outcomes. It supports precise prognostication and survival prediction, facilitates symptom identification and monitoring, and enables personalized, data-driven care planning. DL also strengthens clinical decision-making by recognizing voice and facial expressions, automating documentation through NLP, and streamlining care coordination. Furthermore, it helps assess caregiver risk, optimize pain management, and identify end-of-life care needs. These capabilities empower healthcare professionals to deliver more accurate, timely, and patient-centered palliative care.

2.3.3. Natural Language Processing

Creating algorithms and techniques that allow computers to comprehend, evaluate, and produce human-written and spoken language is known as NLP [53][78][79][80][86]. NLP enables machines to understand and process natural language to simulate human conversation through techniques such as sentiment analysis. It makes performing tasks like sentiment analysis, speech recognition, text summarization, language translation, and natural language generation easier, allowing for more natural interactions between people and machines. [53] [79] [83] [86]. Natural language generation (NLG), the process of creating coherent, machine-generated language, and natural language understanding (NLU), which is concerned with deciphering a text's intended meaning, are the two primary subfields of NLP. Tokenization, text classification, contextual and word embeddings, sequence modeling, machine translation, named entity recognition (NER), summarization, question-answering systems, and dialogue systems are fundamental methods in NLP. The quick developments in NLP and AI have fueled innovations in various applications, such as speech analysis, machine translation, sentiment detection, medical text processing, and more [78].

Furthermore, NLP makes it possible to create chatbots and virtual assistants that can manage and analyze vast amounts of text data while interacting with people naturally [80]. By transforming unstructured human language into structured data, NLP assists robots in extracting context and meaning from complicated language inputs [44]. NLP revolutionizes palliative care by drawing insightful conclusions from unstructured clinical texts, including patient narratives, doctor's notes, and medical records. Clinicians can use these insights to help with advanced care planning, monitoring, symptom diagnosis, prognostic categorization, and clinical record analysis. Additionally, NLP improves automated triage and referral procedures, sentiment and emotion analysis, literature and guideline mining, and communication quality evaluations. These characteristics dramatically enhance patient care and decision-making in palliative contexts. Additionally, NLP facilitates patient portal and chatbot integration and provides multilingual and cross-cultural support.

2.3.4. Computer Vision

One well-known AI method that is essential to the development of computer technology is CV. It allows systems to create well-informed suggestions by extracting useful information from digital photos and videos. This method enables cameras that take the place of the human eye to recognize, distinguish, and analyze objects in images or videos [55]. By creating algorithms that closely resemble the human visual system, CV makes it possible for robots to process and comprehend visual data from cameras and CCTV systems. CV is essential for precise object recognition and actionable insights in various fields, including palliative care, as data availability and processing power grow. The process involves several stages: image acquisition, preprocessing, feature extraction, object recognition, tracking, and interpretation. It starts with capturing images or videos, enhancing or filtering the data, and extracting key features like edges and corners. Objects are recognized by comparing these attributes to a known database, and their movement can be followed over time to give meaningful findings [79]. Key techniques such as classification, object detection, picture segmentation, and facial recognition enable automated visual data analysis, enabling adequate interpretation of images and movies [80].

Computer vision is essential in palliative care because it facilitates automated visual data analysis to improve clinical decision-making. It facilitates technology-assisted communication, pain assessment, mobility tracking, and remote vital sign monitoring. It also helps prevent and detect falls, enhance medication compliance, monitor sleep patterns, support assistive robots for movement, and develop individualized care plans.

2.3.5. Application of AI in Palliative Care

Artificial intelligence is revolutionizing palliative care in the following ways.

- ***AI for early symptom detection and pain management***

AI algorithms, particularly those built on ML, which monitor patient symptoms instantly, make possible more precise evaluations of pain, exhaustion, and other upsetting symptoms typical of palliative care. Predictive models analyze data from various sources, such as physiological signals (e.g., heart rate, blood pressure), clinical records, and self-reported symptoms, to forecast the onset or worsening of symptoms, allowing for early interventions to manage them effectively. For example, Dillon et al. [88] developed an AI-based predictive model for pain management in cancer patients receiving palliative care, which analyzed historical data, including medical history and symptom reporting, to predict pain intensity and optimize early interventions and medication delivery. Additionally, AI algorithms, including NLP and ML, analyze patient-reported symptoms from EHRs and wearable devices to detect early signs of pain, discomfort, and psychological symptoms, aiding in personalized care and comprehensive patient management [29][46]. Tools like IBM Watson have been used to analyze large datasets and predict pain levels. In contrast, AI-driven tools like PainChek use facial recognition technology to assess pain in non-verbal patients, such as those with dementia.

- ***AI-driven prognostic tools for disease progression***

AI models are increasingly used to predict disease progression, helping clinicians and patients make informed decisions about care planning, particularly in palliative care. ML algorithms analyze large datasets of patient characteristics, such as age, comorbidities, laboratory values, and clinical notes, to predict outcomes like survival time and the likelihood of complications. For instance, Gulati et al. [89] developed an ML algorithm using EHRs to predict survival times for advanced cancer patients, demonstrating accuracy in prognosis prediction and supporting healthcare providers in making decisions about care goals and end-of-life planning. Additionally, AI has enhanced tools like the Palliative Outcome Scale to assess functional decline and predict mortality. At the same time, DL models like DeepSurv in oncology have improved survival predictions, enabling more personalized palliative interventions.

- ***AI for personalized care planning***

By combining information from several sources, including genomes, patient preferences, and EHRs, AI personalizes care plans and adjusts palliative care according to each patient's requirements and medical background. AI algorithms help clinicians customize care strategies aligned with patients' goals, including symptom control, quality of life, and end-of-life preferences. For example, Davis et al. [90] developed an AI-powered decision support system that uses patient-reported outcomes to adjust care plans instantly, ensuring a more responsive approach to palliative care. Stanford University's AI tool analyzes patient histories to recommend personalized treatment plans and advance care directives. AI-driven chatbots, like the End-of-Life Companion, provide emotional support and help patients express their care preferences [91].

- ***AI-powered decision support for clinicians***

AI assists healthcare providers in making evidence-based decisions by analyzing and interpreting vast amounts of unstructured text data from clinical notes, medical literature, and patient-reported outcomes using NLP techniques. These systems support symptom management, treatment strategies, and decision-making by extracting actionable insights from EHRs and other clinical documents. For instance, in palliative care, AI-powered NLP tools have been used to extract relevant clinical data from unstructured notes to guide decisions, such as whether a patient should receive aggressive treatments or transition to comfort care [92]. Additionally, AI models like OncPal suggest personalized opioid dosages for cancer patients, enhancing pain relief while minimizing the risk of overprescribing [93]. AI-driven clinical decision support systems, including palliative care dashboards, integrate patient data to provide real-time recommendations [46][47].

- ***AI in end-of-life care communication***

AI-powered NLP tools analyze patient conversations and clinical notes to identify preferences for end-of-life care. For instance, the VOICE AI project has analyzed physician-patient interactions to enhance shared decision-making in palliative care [94]. Additionally, AI-driven speech analysis tools detect signs of distress in terminally ill patients and recommend appropriate psychological interventions.

- ***AI and virtual health assistants in home-based palliative care***

Robotic systems enhanced with AI are increasingly used in palliative care to assist with physical tasks like lifting, monitoring vital signs, and offering companionship. These systems help ease the physical strain on caregivers, enabling them to focus more on emotional support and communication. For instance, Zhou et al. [95] demonstrated how an AI-powered robotic system provided companionship and monitored the mental health of elderly palliative care patients. The system used ML to detect changes in behavior and mood, alerting caregivers when intervention was needed. Additionally, AI-driven virtual assistants and remote monitoring systems support patients at home, such as the Catalia Health system, which utilizes robots like Mabu to engage patients, track symptoms, and offer emotional support. Wearable AI devices like the Oura Ring monitor vital signs and notify caregivers of any health deterioration.

- ***AI for bereavement support and family counseling***

AI goes beyond patient care by offering bereavement support to families. For instance, AI-driven chatbots such as GriefBot provide psychological counseling and personalized assistance to grieving families [96]. AI sentiment analysis tools assess caregivers' emotional distress and suggest timely interventions. Fig. 3 summarizes the application of AI in palliative care.

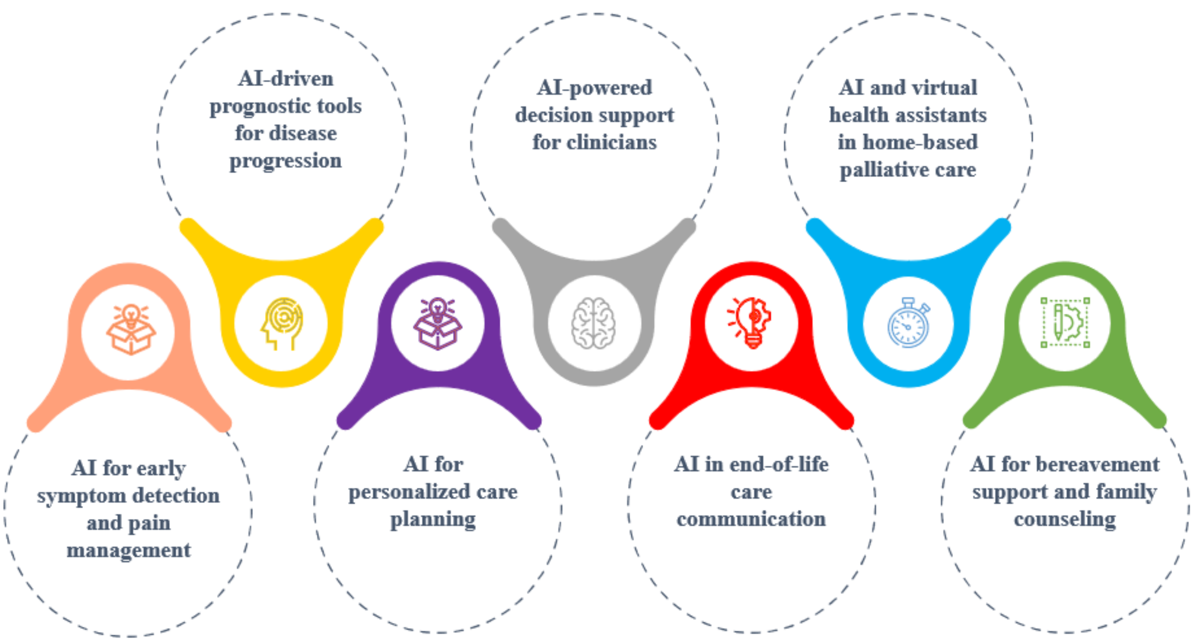

Fig. 3. Summary of the application of AI in palliative care.

AI applications in advanced robotics offer several key advantages. These technologies automate repetitive tasks, freeing human resources for more complex duties. They enhance the accuracy and precision of robotic systems, reducing errors and improving performance. AI-powered robots adapt to changing environments and tasks, boosting their versatility across various industries. ML algorithms predict maintenance needs, minimizing downtime and creating cost savings. Moreover, AI and ML enable robots to analyze large datasets, improving decision-making and overall efficiency by optimizing processes, reducing waste, and increasing productivity. These advancements also enhance workplace safety by automating dangerous tasks, minimizing the risk of accidents, and lowering labor and maintenance costs [81].

3. ARTIFICIAL INTELLIGENCE-DRIVEN ROBOTICS

AI-powered robotics represents a breakthrough in the digital transformation of the health sector, driving the creation of intelligent robots with advanced capabilities [25][32]. Li et al. [34] and Licardo et al. [38] describe AI-powered robotics as physical systems that combine AI with advanced sensing technologies to perceive their surroundings autonomously, interact with the environment, learn from experience, adapt to new conditions, and make decisions. As AI and sensing technologies continue to advance, these integrated systems will increasingly take on more complex roles and drive new opportunities for innovation [38]. AI-powered robotics in palliative care involves using intelligent robotic systems equipped with technologies like ML, DL, NLP, CV, and autonomous decision-making, enabling robots to perform complex tasks with greater efficiency, adaptability, and intelligence and improving the QoL for patients with severe or terminal illnesses. These systems support pain management, provide emotional comfort, monitor patient conditions, assist with mobility, and aid caregivers, enhancing the overall efficiency and effectiveness of palliative care. Fig. 4 illustrates AI-powered robotics in Palliative care.

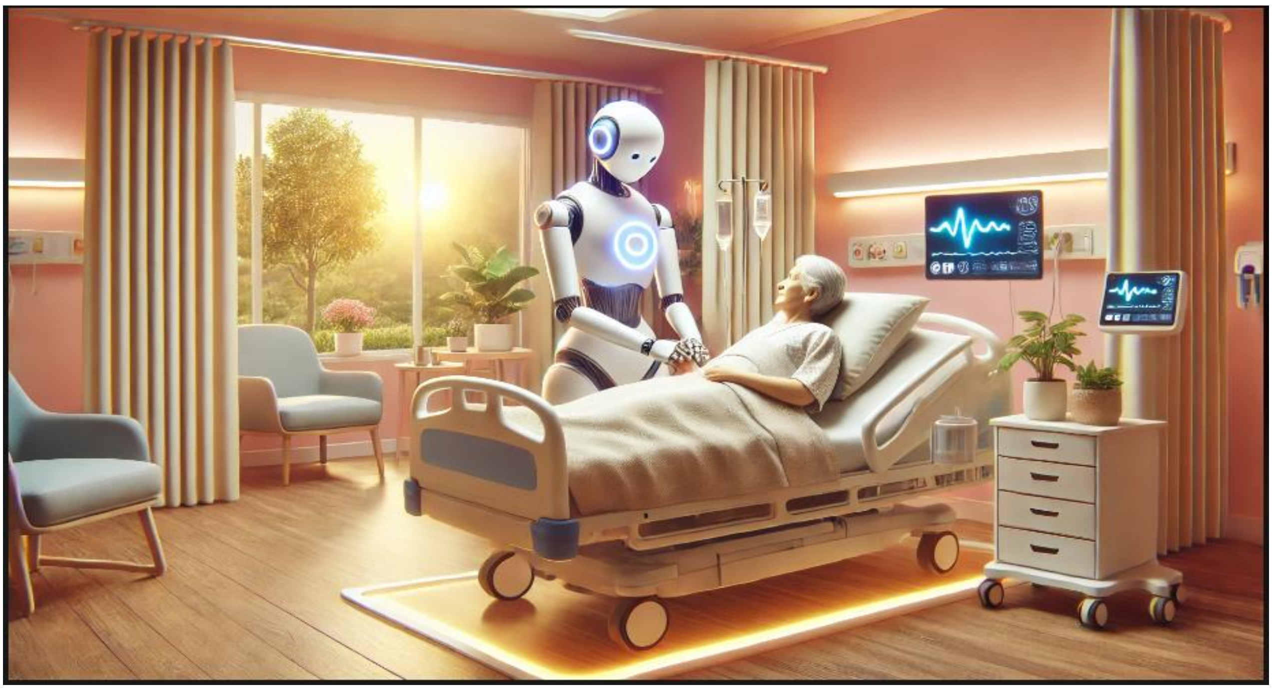

Fig. 4. Illustrates AI-powered robotics in Palliative care [97].

By 2050, an estimated 4 billion AI robots will operate among us. The AI robotics market is projected to reach US$22.63 billion in 2025 and grow at a compound annual rate of 26.82% between 2025 and 2031, reaching a projected volume of US$94.14 billion by 2031. The United States is expected to lead globally, with a market size of US$9.49 billion in 2025. The COVID-19 outbreak in 2020 sparked an unexpected surge in demand for AI robots, accelerating the integration of "Healthcare + AI + Robotics" technologies. These robots were crucial in lowering the danger of infection for frontline healthcare workers and halting the virus's spread [34].

Thanks to the integration of AI algorithms and ML techniques, robots can now learn, adapt, and interact with the world in previously considered science fiction ways. This progress results from a dynamic partnership between AI and human ingenuity, propelling the creation of autonomous vehicles, drones, and robots that will transform exploration, healthcare, and transportation. AI gives robots adaptability and learning power, changing how they interact with people. As a result, the combination of robotics and AI is bringing about a paradigm shift in which machines serve as companions and cognitive extensions of human potential in addition to being tools [32]. Continuous vital sign monitoring is made possible by AI-driven wearable technology and robotic systems, which lower medical risks and allow for prompt interventions [35][98]. Several essential elements are included in AI-powered robotics to improve performance and usefulness. Sophisticated AI systems power learning, perception, and decision-making. While ML enables robots to learn from experience, DL uses neural networks to process large datasets, such as image recognition and language processing. Reinforcement learning will allow robots to learn from their mistakes and improve their behavior, while CV helps them comprehend visual input for facial recognition and object detection. NLP improves communication by assisting machines in understanding and producing human language. Robots employ sensors such as LiDAR for 3D mapping and navigation, cameras for image recognition, infrared sensors for motion and heat detection, and proximity and touch sensors for tactile interaction to sense their environment. Actuators convert electrical impulses into motion using servo motors, hydraulic and pneumatic systems, and soft robotics, enabling precise, powerful, or delicate motions as needed. Cloud computing offers large-scale data processing, whereas edge AI enables real-time, on-device decision-making, improving responsiveness and efficiency.

Advanced sensor technologies, AI, ML, and DL are driving a radical transformation in robotics by enhancing productivity, accuracy, and flexibility. Robots equipped with sensors can perceive and interact with their environment. AI and ML enable them to analyze vast amounts of data, adapt their behavior in real-time, and learn from their mistakes. This adaptability is necessary to meet the evolving demands of industrial applications and boost productivity across various industries. Additionally, intelligent robotics—which prioritizes complex cognitive processes and seamless human-machine interaction—is developed with the help of these technologies. As research and industry advance, utilizing AI, ML, and DL will expand robots' capabilities and potential applications. Current applications include autonomous navigation, object detection and manipulation, NLP, predictive maintenance, and the development of cobots, which operate safely and effectively alongside humans in dynamic environments [38][81].

Machine learning transforms robots in palliative care by enabling intelligent automation, personalized support, and predictive healthcare interventions. Two examples of ML algorithms that employ real-time anomaly detection, vital sign monitoring, and historical data analysis to predict the progress of an illness are Support Vector Machines (SVM) and Random Forests (RF). Techniques like Principal Component Analysis (PCA), Autoencoders, and K-means clustering enable the recommendation of tailored care and the discovery of behavioral patterns that anticipate the need for care by categorizing patients based on their symptoms and responses to therapy. DL transforms robotics in palliative care by allowing the robots to process complex data, adapt to the needs of each patient, and offer more perceptive and compassionate support. CNNs, YOLO, and Faster R-CNN are examples of DL algorithms that analyze body language and facial expressions to detect motions for nonverbal communication, measure pain levels, and identify real-time symptoms like fatigue or discomfort.

Algorithms like Deep Q-Networks (DQN), Proximal Policy Optimization (PPO), and Actor-Critic Methods are used to train robotic assistants to navigate care environments safely, interact with patients more effectively, and adjust routines in response to feedback and evolving medical situations. Recurrent neural networks (RNNs), transformer models (GPT, BERT, and T5), and long short-term memory (LSTM) allow robots to have meaningful conversations, perform sentiment analysis to identify emotional distress and use speech-to-text for hands-free documentation. These algorithms also track vital indicators, predict pain levels, and recommend customized measures by evaluating historical and present data. In addition to customizing robotic responses and modeling care scenarios, Variational Autoencoders (VAEs) and Generative Adversarial Networks (GANs) automate essential tasks, including feeding, medication reminders, and hygiene support. Attention-based networks and Vision Transformers (ViTs) significantly enhance video-based diagnostics, continuous monitoring, anomaly detection in home care settings, and remote consultations by assessing medical images and patient scenarios.

NLP is transforming robots in palliative care by improving patient interactions, automating administrative tasks, and providing emotional support. When NLP is included in robotic systems, palliative care becomes more patient-centered, efficient, and supportive, crucial for raising patients' quality of life and reducing the burden on caregivers. Critical applications include sentiment analysis, automated documentation, and speech recognition. NLP algorithms like DeepSpeech (Mozilla) and Whisper (OpenAI) have enabled robots to transcribe and understand spoken language effectively, improving communication for those with speech difficulties. RNNs and Hidden Markov Models (HMMs), which process continuous speech, improve voice command recognition. Bidirectional Encoder Representations from Transformers (BERT) and LSTM networks simultaneously detect emotions in patient speech or text, assisting robots in identifying pain, discomfort, or agony. Transformer-based models enable humanlike and empathetic dialogues to revolutionize palliative care by improving safety, increasing patient monitoring, and offering customized care. Palliative care outcomes could be transformed by CV in robotics, which would also lessen the effort of human caregivers. These algorithms allow robots to assess patient needs, decipher visual cues, and assist with daily tasks, resulting in more efficient, responsive, and customized care. Therefore, the general standard of care in palliative settings can be significantly enhanced by robots. AI-driven robotic technologies are revolutionizing palliative care by enhancing patient comfort, emotional support, and healthcare efficiency. These systems monitor patients, automate tasks, manage symptoms, and improve communication through sophisticated robotics, ML, and DL.

AI has allowed robots to sense and engage with their surroundings, form opinions, and do complex tasks like item identification, speech and image recognition, and real-time data analysis. AI-driven robots provide individualized care and assist caregivers by adapting to changing circumstances through constant learning from experience. AI in robots can optimize medical operations, provide personalized remedies, and enable access to remote or dangerous areas, such as disaster areas. This technology enhances patient outcomes, transforms healthcare delivery, and encourages innovation in the sector. Addressing ethical and societal issues is crucial as AI and robotics develop to guarantee their responsible use and maximize their potential to enhance patient care and healthcare efficiency [28][32][48][81][84].

3.1 Types of AI-Powered Robots in Palliative Care

Based on their primary functions, AI-powered robotics in palliative care can be categorized into various categories.

3.1.1. Assistive robotics

Assistive robotics in palliative care refers to using robots to help patients with daily duties, improve their quality of life, and support patients and caregivers. These robots assist with movement, personal hygiene, and daily tasks. AI-powered robotic exoskeletons and wheelchairs, for instance, help people with mobility impairments stand or walk more easily, reduce the risk of bedsores, and enhance their physical well-being. The need for caregivers is reduced when patients receive assistance with eating and personal hygiene, feeding, and hygiene aides, such as automatic feeding robots and robotic arms. AI-enhanced novel prostheses help patients restore motor functions by adapting to their movement patterns. Additionally, therapeutic robots that resemble baby seals, like Paro, provide emotional support and company, which lessens feelings of loneliness and anxiety. By performing these duties, assistive robots significantly increase the comfort and independence of palliative care patients.

3.1.2. Companion and social robotics

The goal of social and companion robotics in palliative care is to improve social contact, reduce feelings of loneliness, and provide patients with life-threatening illnesses with emotional support. These robots enhance patients' mental health by interacting with them and providing companionship. For example, Paro, a therapeutic robot that looks like a baby seal, has been widely used in palliative care settings to reduce patients' anxiety and suffering. It can improve a patient's mood and reduce loneliness because it behaves like a real pet and responds to touch, sound, and light. Similarly, social robots like Pepper are designed to play games, talk to patients, and remind them of appointments or prescriptions. These robots can reduce the need for constant human monitoring while fostering fundamental social interactions. AI-powered cognitive stimulation robots offer amusement, memory exercises, and reminders to individuals with dementia or cognitive decline. Additionally, therapeutic pet robots may help people with chronic illnesses feel more relaxed and less stressed. Interactive, soft robotic pets that mimic the emotional well-being and quality of life of palliative care patients are crucial for enhancing palliative care patients' quality of life by encouraging social interaction and emotional connection.

3.1.3. Monitoring and diagnostic robotics

Palliative care monitoring and diagnostic robotics use robots and automated systems to track patients' health, monitor vital signs, and assist with diagnostic tasks to improve patient care and aid in medical decision-making. These technologies enhance the ability of caregivers and medical professionals to recognize changes in a patient's status by facilitating prompt actions. For example, robotic devices can monitor vital signs such as heart rate, blood pressure, oxygen saturation, and temperature, providing real-time information to medical professionals and caregivers. Wearable sensors with robotic support that continuously monitor patient measures and alert users to unusual findings are a relevant example. Robots occasionally analyze patient data using AI and ML algorithms to identify patterns and predict potential health issues—such as infections or respiratory complications—before they worsen. Medical teams can use diagnostic robots, such as robotic endoscopes, to assist with non-invasive treatments like gastrointestinal examinations and perform necessary tests without invasive surgeries. These robotic gadgets ensure patients' safety, comfort, and well-being in palliative care by providing continuous monitoring and diagnostic support. Remote monitoring robots have sensors that monitor vital signs and alert caregivers to changes in patient conditions. When AI-enhanced fall detection and safety robots identify falls or other emergencies, they automatically notify family members or medical personnel. "Pain assessment robots" are AI-powered machines that use facial expressions, body language, and speech cues to gauge the level of pain experienced by non-verbal patients.

3.1.4. Procedural and service robotics

"Procedural robotics" in palliative care refers to robots that help with medical procedures and carry out duties that increase the precision and effectiveness of healthcare delivery. These robots can improve patient outcomes while reducing the physical strain on medical personnel by doing routine duties like medication delivery, vital sign monitoring, and diagnostic assessments. For example, less invasive surgeries can benefit from robotic technology like the da Vinci Surgical System, which allows for greater accuracy and faster recovery and works exceptionally well in palliative care situations when comfort and recuperation are essential. Service robotics focuses on non-medical tasks to improve the' daily lives of patients receiving palliative care. In addition to being friends, these robots handle cleaning, entertaining, and organizing. For instance, robotic vacuum cleaners might be able to keep a patient's environment tidy with minimal human help. Concurrently, social robots that offer emotional support to lessen loneliness and distress include Paro, a therapeutic baby seal robot. Jibo is a social robot that may engage with patients through conversation, reminders, or mild amusement to support mental and emotional well-being. These service robots are crucial to palliative care because they relieve caregivers and enhance patients' overall quality of life. AI-powered gadgets and robots that distribute and arrange medications based on individual schedules can reduce medication errors. Doctors can consult with patients and caregivers from a distance using telepresence and remote-controlled robots with video conferencing capabilities. Robotic surgical assistants, also known as AI-assisted surgical and therapeutic robots, aid with procedures like tumor excision or palliative care that lessen agony or improve the quality of life for patients.

3.1.5. Nursing assistance robots

Nursing aid robots help patients and medical personnel in palliative care by performing tasks that improve patient comfort and lessen caregiver workload. Routine tasks like administering medication, monitoring vital signs, and physically helping patients move about in bed are made easier by these robots. For example, the Robear robot is a nursing assistive robot that lifts and moves patients to relieve the physical strain on caretakers. It can help move a patient from a bed to a wheelchair or from a lying to a sitting position, increase patient comfort, and decrease caregiver injuries. Another example is the Telenoid robot, a telepresence device that allows caregivers or loved ones to engage with patients while offering emotional support and companionship from a distance. When Telenoid imitates human gestures and facial expressions, it can make interactions with patients undergoing palliative care more personal and comforting. Intelligent robots alleviate some of the physical burdens of nursing labor, allowing nurses to concentrate on more professional and thorough nursing chores [34].

3.1.6. Rehabilitation assistance robots

Rehabilitation assistance robots aim to improve patients' quality of life, promote mobility, and aid in restoring or preserving physical capacities. These robots help persons with incapacitating conditions, like chronic illness or severe diseases, with daily tasks, mobility, and physical rehabilitation. One example is wearable technologies such as robotic exoskeletons, which let persons with severe mobility impairments stand, walk, or regain some degree of mobility. These robots can increase muscle mobility and provide physical therapy by preventing muscular atrophy and boosting circulation, which reduces the risk of issues like bedsores. For instance, the ReWalk exoskeleton helps people with lower limb paralysis stand and walk, which improves their physical health and independence. They assist with specific therapy tasks. For example, exercises to restore upper body strength and joint mobility can benefit from using robotic arms. Arm movement is improved by devices like the ArmeoSpring system, which provides resistance and support during rehabilitation exercises. Passive-moving robots—like the MIT-Manus robot—assist patients with limited voluntary movement by guiding their arms through rehabilitative motions that promote joint health and muscle activation. These robots can now provide physical therapy to patients in palliative care without the constant manual aid of caretakers. These rehabilitation support robots in palliative care enable patients to engage in physical therapy, regain or preserve movement, and maintain a sense of autonomy while reducing the burden on caregivers [34]. Fig. 5 summarizes the main types of AI-powered robots in palliative care.

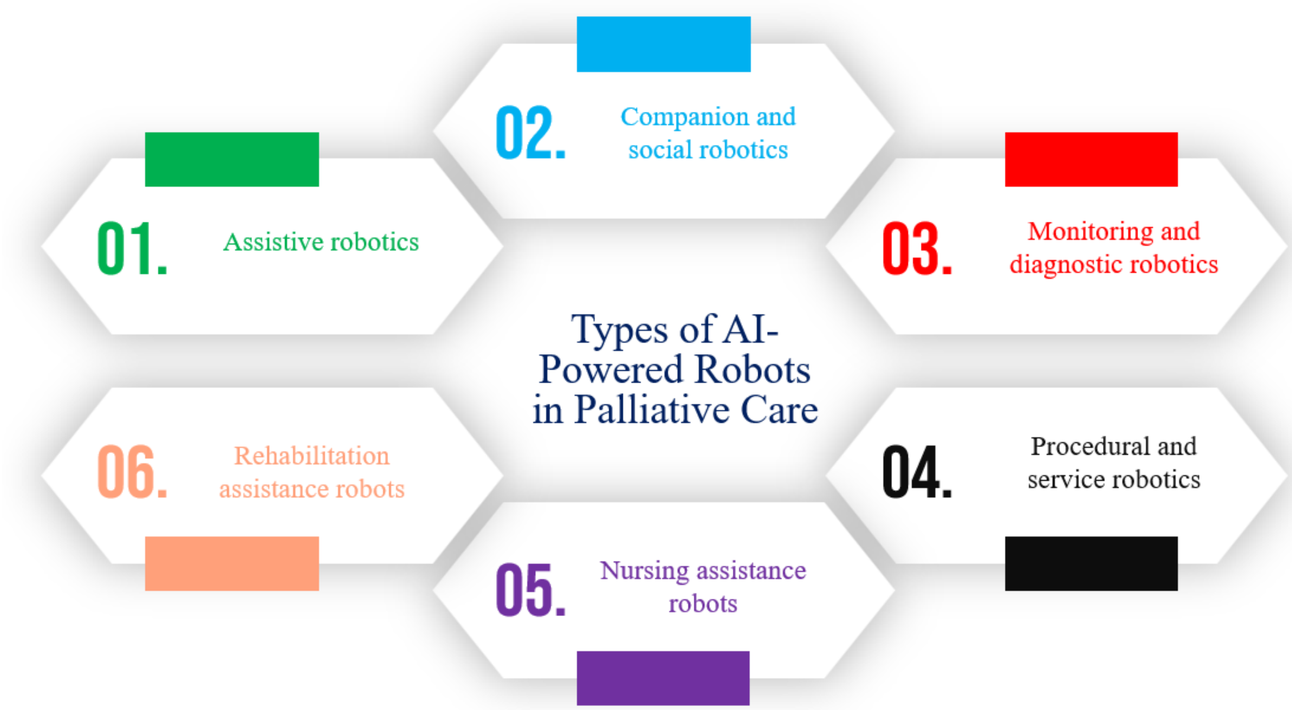

Fig. 5. Summary of the main types of AI-powered robots in palliative care.

3.2 Application of AI-Powered Robotics in Palliative Care

Table 1 briefly describes the applications of AI-powered robots in palliative care.

TABLE I. BRIEF DESCRIPTIONS OF THE APPLICATIONS OF AI-POWERED ROBOTS IN PALLIATIVE CARE.

S/No	Application	Brief Description
1	Companion robots for emotional support	AI-driven companion robots, such as the robotic seals PARO and Pepper, support palliative care patients by reducing loneliness, anxiety, and emotional distress. Patients are comforted by PARO's interactive activities in response to touch and voice. In parallel, PARO and Pepper use NLP to converse and encourage social and cognitive interaction. According to clinical research, some dementia patients may experience a 30% reduction in anxiety and medication use as a result of PARO interactions. Additionally, these robots benefit those suffering from cognitive decline, improving their quality of life while receiving end-of-life care. AI systems also increasingly monitor patients' psychological health by analyzing speech patterns, facial expressions, and physiological data to identify early indicators of anxiety, despair, or discomfort, allowing medical professionals to intervene successfully and quickly [68][98-100].
2	Telepresence robots for remote consultations	Healthcare providers can use telepresence robots to conduct remote consultations, allowing continuous patient monitoring without being physically present. The National Robotarium in Scotland developed a prototype AI-powered telepresence robot that enables practitioners to remotely monitor patients with dementia or Alzheimer's disease, respond to emergencies, and deliver timely assistance.
3	Remote care assistance	Companies like Robody have created humanoid robots that caregivers can remotely operate to assist elderly individuals. These robots perform tasks such as fetching medication, preparing meals, and offering companionship through physical interactions like hugs. They also monitor vital signs and can alert caregivers or emergency services when needed, helping seniors maintain their independence while ensuring they receive essential support.
4	Robotic assistance in daily activities	AI-powered robots, like Robody, developed by Devanthro, support palliative care patients by assisting with routine tasks such as fetching medication, preparing meals, and dressing. These robots enable elderly individuals to retain their independence while receiving essential care. They aid with daily activities and provide therapeutic interactions and emotional support, mainly through robotic animals. These robots have effectively reduced medication use and enhanced emotional well-being in palliative care settings [31].
5	Medication reminders and monitoring	In the UK, care providers such as Cera Care are trialing robots that remind patients to take their medication and eat and drink regularly. These robots also facilitate connections between patients, their families, and caregivers and can alert staff if patients remain unresponsive for extended periods. By handling routine tasks, this technology enables caregivers to prioritize in-person visits for acute cases, ultimately improving care efficiency.
6	Pain management through automated drug delivery	AI-powered automated drug delivery systems administer precise medication doses to palliative care patients, ensuring consistent pain relief. These systems minimize human error and maintain optimal patient comfort levels throughout their care.
7	Predictive modeling and decision support	AI applications in palliative care use predictive modeling to forecast clinical outcomes, such as short-term mortality risk and the need for supportive care services. These tools support clinicians in making informed decisions, reduce manual workload, and have the potential to improve care outcomes [29][33].
8	Physical assistance	An AI-powered robot nurse called Airec was first released in Japan and helps the elderly change their clothes and positions. These robots, which were created to aid an aging population, lessen the physical strain on human caretakers by offering the necessary support.
9	Social interaction enhancement	The Hyodol robot in South Korea is a companion robot created to improve patient social contact. Hyodol is a device made to help the elderly by tracking their activities and reminding them to take their meds. It recognizes and reacts to emotional states, providing companionship and individualized care essential in palliative care settings.
10	AI chatbots for patient education and symptom management	AI chatbots support patients by providing information about their condition, educating them on disease progression, and helping them recognize and manage symptoms. They offer round-the-clock assistance, guiding patients on when to seek medical attention and how to handle common symptoms.
11	Robotic exoskeletons for mobility support	Researchers from the RIKEN Guardian Robot Project developed a robotic exoskeleton to help palliative care patients with mobility impairments. This exoskeleton enables individuals to move independently and engage in daily activities, significantly improving their quality of life.
12	Cognitive stimulation	Robots like Moxie engage patients in cognitive activities to stimulate mental functions and delay cognitive decline. By interacting with patients through conversations and activities, these robots provide valuable mental engagement, which is especially beneficial in palliative care.
13	Monitoring and alert systems	AI-powered robots with sensors monitor patients' vital signs and movements, alerting caregivers to abnormalities. This continuous surveillance enables timely interventions, improving patient safety and the quality of care in palliative settings.
14	AI-powered monitoring systems for vital signs	AI-integrated monitoring systems instantly track patients' vital signs and immediately alert caregivers to significant changes. For instance, the Ally Cares system uses infrared and acoustic monitoring to detect issues such as infections, enabling prompt medical intervention.
15	Robotic pets for therapeutic engagement	Robotic pets like Moflin, an AI companion developed by Casio, mimic the emotional responses of real animals to provide companionship and reduce anxiety in palliative care patients. These robots adapt their personalities through interactions, delivering personalized emotional support.
16	AI decision support tools for end-of-life planning	AI decision support tools help healthcare providers plan end-of-life care by analyzing patient data to predict outcomes and suggest appropriate care strategies. For example, the Hospital One-year Mortality Risk (HOMR) application calculates the 12-month mortality risk for newly admitted patients, enabling timely discussions about palliative care.
17	Rehabilitation support	AI-powered robots guide patients through physical therapy routines, assisting with rehabilitation exercises. This support helps maintain mobility and physical function, enhancing the overall well-being of palliative care patients.

18	Robotic assistance for caregivers	AI-powered robots help alleviate caregiver burdens by performing repetitive tasks like lifting and transferring patients. Robots like RIBA and Robear are specifically designed to lift patients safely from beds to wheelchairs, reducing physical strain on caregivers and minimizing the risk of injury.
19	Pain and symptom management	AI algorithms enhance pain assessment and symptom management in palliative care by analyzing physiological data and patient reports. AI-powered robotic systems accurately deliver medication, monitor vital signs, and adjust real-time treatment plans. These robots can predict pain episodes by processing continuous patient data and recommend or autonomously administer pain-relief interventions, enabling personalized and timely care [67][101]. This precision reduces the risk of under or over-treatment, which is critical for ensuring comfort at the end of life [102]. Robots like RIBA, a "Smart Home Robot," assist with repositioning patients, offering comfort, and tracking vital signs like heart rate and respiration. AI-driven robots handle repetitive tasks, freeing medical professionals to concentrate on intricate clinical judgments and eventually enhancing the effectiveness and quality of palliative care.

3.3 Real-World Examples and Case Studies of AI-Powered Robotic Technology in Palliative Care

Below are real-world examples of AI-powered robots in palliative care that demonstrate how these tools assist with end-of-life care in diverse contexts.

3.3.1. PARO Therapeutic Robot (Japan)

Paro is a therapeutic robot that resembles a baby seal and uses integrated sensors to respond to touch, movement, and sound. It creates interactive experiences that reduce agitation, anxiety, and depression by using sound and motion to express emotions, particularly in elderly patients receiving palliative care or those suffering from chronic illnesses. Studies have shown that Paro decreases loneliness by enhancing social contact and fostering nonverbal connections. Additionally, by providing a calming, restorative presence, Paro helps caregivers feel less stressed [103].

3.3.2. Robear (Japan)

Robear is a robotic assistant in palliative care that helps caregivers move and lift patients, especially those with limited mobility. It uses AI to assess a patient's strength and body type, allowing for safe and efficient transfers. By reducing the physical strain on caregivers, Robear enhances comfort and safety for those with advanced illnesses and facilitates patient mobility [104].

3.3.3. ElliQ (Israel)

ElliQ is a social robot that provides older individuals, especially those who are elderly or have chronic illnesses, with companionship, emotional support, and stimulating conversation. AI offers timely reminders, cognitive stimulation, and knowledge of user requirements and preferences. By lowering social isolation and daily routines, ElliQ assists palliative patients in managing social isolation, a prevalent issue in end-of-life care [105].

3.3.4. Lio Robot (United Kingdom)

Lio is a portable AI-powered robot that monitors and assists people with severe chronic conditions like cancer by tracking their vital signs, recording their health data, and sending their real-time analysis to medical specialists. By providing early insights and facilitating continuous monitoring, Lio enhances care coordination for palliative patients and notifies doctors of changes in patient conditions [106].

3.3.5. Softbank Robotics Pepper (Global)

A humanoid robot, Pepper, communicates with people by recognizing and responding to their emotions. In medical settings, especially palliative care, it offers patients with terminal illnesses companionship and emotional support. Pepper connects with patients through emotional cues and conversation, which helps them manage their diseases and lowers their anxiety [107].

3.3.6. Jibo (United States)

Jibo, a social robot, engages users through interactive conversations with cognitive stimulation and companionship. Designed to assist those with mobility challenges or chronic illnesses, Jibo can be combined with several health monitoring systems to enhance care. Voice and movement might help palliative patients feel emotionally supported and engaged cognitively, even though they often feel alone [108].

3.3.7. Mylo Robot (Canada)

Mylo is a telepresence robot facilitating remote communication for patients receiving palliative treatment. With AI capabilities, it adjusts its movements and interactions to foster strong bonds between patients, their families, and healthcare providers. By facilitating virtual contact, Mylo helps patients who cannot receive in-person assistance at the end of their lives feel less alone and lonely [109].

3.3.8. Mabu Healthcare Companion Robot (United States)

Seniors, including those undergoing palliative care, can receive emotional support and health monitoring from Mabu, a medical companion robot. Through conversational AI, it engages patients, monitors their symptoms, reminds them to take their meds, and promotes social interaction. By assuming these duties, Mabu eases the burden on caregivers and promotes patients' emotional well-being [110].

3.3.9. RoboNurse (Germany)

An AI-powered robot called RoboNurse helps patients nearing the end of their lives by taking care of their prescriptions, conducting regular health examinations, and offering company. It regularly monitors patients and helps with everyday duties to ensure their demands are effectively satisfied. RoboNurse frees caregivers to focus on more intricate parts of care by taking care of monotonous tasks [111].

3.3.10. Telenoid (Japan)

The Telenoid is a robot designed to facilitate telepresence communication, particularly for patients in palliative care. Leveraging AI enhances communication, making interactions more natural and comforting for patients who cannot engage. The Telenoid helps bridge the isolation caused by a patient's condition, enabling more personal interactions with family members or healthcare providers, which is essential for emotional well-being in end-of-life care [112].

3.3.11. Lokomat

The Lokomat, an exoskeleton robotic system, is widely used in rehabilitation to assist patients with movement impairments, including those in palliative care. By providing robotic-assisted gait training, the system enables patients to perform walking exercises that would otherwise be difficult. Though not initially designed for palliative care, it has been adapted to support mobility for patients with terminal illnesses or advanced chronic conditions, helping them maintain independence and improve their quality of life [40][113].

3.3.12. Robo-Pharmacy System

The Robo-Pharmacy System is an AI-powered robotic medication dispenser designed for integration into palliative care environments. It automatically prepares and delivers the correct medication doses, minimizing the risk of human error and ensuring precise medication delivery, which is particularly crucial for managing pain, nausea, and other distressing symptoms in terminally ill patients [114].

3.3.13. Care-o-bot

Care-o-bot is a service robot designed for long-term and palliative care environments. It monitors patients' health data, reminds them to take medications, and notifies healthcare providers if a patient's condition worsens. Equipped with AI, it assesses emotional and physical health, offering companionship while ensuring the collection and transmission of essential medical data to caregivers [115].

4. CHALLENGES ENCOUNTERED BY AI-POWERED ROBOTS IN PALLIATIVE CARE

Table 2 briefly describes the challenges in integrating AI-powered robots into palliative care.

TABLE II. BRIEF DESCRIPTIONS OF THE CHALLENGES ENCOUNTERED WHILE INTEGRATING AI-POWERED ROBOTS INTO PALLIATIVE CARE.

S/No	Challenges	Brief Description	References
1	Ethical concerns	Deploying AI-driven robotics in palliative care introduces significant ethical challenges requiring careful consideration to ensure responsible and human-centered integration. Central concerns include informed consent issues that become even more pressing in low-resource settings that lack adequate infrastructure and regulation. Patients must clearly understand the capabilities and limitations of AI systems to make informed decisions, a task complicated when cognitive capacity is diminished. AI tools, while offering potential benefits such as personalized interaction through ML and NLP, often lack the emotional warmth of human caregivers, raising concerns about trust and empathy in end-of-life care. These technologies rely heavily on sensitive data, and mishandling it can lead to serious ethical and legal breaches.	[32][33][44] [45][116][117]
2	Data privacy and security	Large volumes of sensitive patient data are collected and processed by AI robots in the healthcare industry, raising serious privacy and security issues, particularly in fields like palliative care. These systems often use surveillance tools and wireless data transmission to monitor patients, which, while enhancing safety, can infringe on privacy and compromise confidentiality. Unauthorized access or data breaches violate patient trust and expose healthcare providers to legal and ethical risks. The absence of clear standards to define safety and accuracy further complicates the deployment of AI robots, as narrow technical measures alone cannot address these challenges.	[34][45]

3	AI algorithmic bias	AI systems in palliative care can introduce significant challenges, especially when trained on non-representative data. This can lead to biased treatment recommendations and disparities in care quality for minority groups. These systems may generate incorrect predictions or decisions, directly affecting patient outcomes. Their lack of transparency raises concerns, especially in ethically complex, highly individualized end-of-life care.	[45]
4	Technical complexity and limitations	AI-powered robots in palliative care face several technical limitations that affect their reliability and effectiveness. These systems often struggle with fine motor tasks, such as dressing or cooking, reducing their ability to deliver comprehensive care. Their complexity can also hinder adoption, as healthcare providers may find them challenging to understand and use without sufficient training and support. Technical challenges related to system reliability, cost-effectiveness, and resource allocation must be addressed to ensure successful deployment. Despite recent advances, AI robots still require improved accuracy, adaptability, and contextual awareness to operate effectively in dynamic care environments. Enhancing sensor fusion and DL is essential for better real-time decision-making. Furthermore, biased AI algorithms—often trained on incomplete or unrepresentative data—can lead to disparities in care, as demonstrated by a 2023 study where a predictive model failed to deliver accurate results for minority groups. Malfunctions in robotic systems assisting with mobility and physical tasks may also pose safety risks to vulnerable patients.	[35][41-43]
5	Resource limitations	Implementing and maintaining AI and robotics in palliative care demands substantial financial investment, including hardware, software, infrastructure, and specialized training costs. Healthcare institutions must assess whether such investments are financially sustainable or if they divert essential resources from other critical services. The need for reliable infrastructure—such as stable internet connectivity and power supply—further increases the overall cost. These financial and logistical demands often exceed the capacity of publicly funded systems or low-resource settings, particularly in rural or underserved areas. These constraints remain significant barriers to adopting AI technologies in healthcare.	[41][42][118]
6	Regulatory challenges and implications	As AI-powered robotics continue to expand across sectors like healthcare, robust regulatory frameworks become essential for guiding their responsible development and deployment. Ethical concerns—data privacy, algorithmic bias, and liability for AI errors—demand urgent attention to ensure safe and equitable use. In sensitive fields such as palliative care, existing regulations fail to address the unique ethical, privacy, and safety issues.	[32][116]
7	Lack of data standardization and interoperability	To be effective in palliative care, AI requires access to high-quality, standardized data across diverse healthcare settings. However, fragmented data—spread across hospitals, hospices, and home care—poses a significant barrier to seamless AI integration. A 2024 report by Maguraushe and Ndlovu emphasized that poor interoperability between healthcare systems prevents AI from synthesizing diverse patient information, limiting its ability to enhance care. Without standardized and connected data, AI tools cannot deliver the comprehensive insights needed to address the complex needs of palliative care patients.	[27]
8	Training and acceptance among healthcare providers	The insufficient training of healthcare providers in AI and robotics poses a significant challenge, as many palliative care professionals are unfamiliar with these technologies and hesitant to integrate them into their practice. A 2020 survey revealed that healthcare workers often resist adopting AI tools, fearing that these technologies might complicate patient care or weaken the patient-provider relationship.	[119]
9	Patient acceptance and psychological barriers	Interacting with robotic systems or AI can evoke emotional discomfort in patients, particularly those in the advanced stages of illness. A 2021 study on social robots found that while some patients found comfort in robotic companions that alleviated loneliness, others felt uneasy about technology replacing human caregivers. This discomfort creates psychological barriers that hinder patient engagement with these technologies. Fear of dehumanization and reluctance to embrace non-human interactions can prevent the widespread adoption of AI and robotics in palliative care settings.	[39][61]
10	Cultural and social acceptance challenges	The acceptability of AI and robotics in palliative care is greatly influenced by cultural views, which frequently frame these technologies through cultural norms related to privacy, death, and caregiving. In some cultures, AI-driven care is seen as impersonal or lacking empathy, with a preference for human caregivers. A 2021 study by He et al. revealed that patients from specific cultural backgrounds perceive robots as “cold,” contributing to resistance toward technological interventions in caregiving. In countries like Japan and Germany, where elder care traditions are deeply rooted, social stigmas against robotic caregivers intensify this resistance.	[39][119]
11	Difficulty in developing accurate, generalizable predictive models	Developing AI models that accurately predict the diverse needs of palliative care patients presents a significant challenge due to this complex and varied nature, which often includes individuals with multiple comorbidities. A 2023 study highlights that AI systems frequently struggle to generalize across different patient groups, limiting their effectiveness in palliative care. Furthermore, the absence of comprehensive and standardized palliative care data complicates the development of reliable models, reducing the ability of AI to predict patient needs and outcomes effectively.	[101][120]

12	Integration challenges with existing healthcare infrastructure	Integrating AI and robotics into healthcare systems presents a significant challenge, particularly in rural and resource-poor areas, where many healthcare facilities lack the digital infrastructure to support these technologies. A 2023 review by Maguraushe & Ndlovu highlights the insufficient IT resources and inadequate staff training in hospice and home care settings, which hinder the effective maintenance and troubleshooting of AI and robotic systems. Additionally, the incompatibility between AI systems and existing EHR systems complicates the seamless exchange of patient data, which is essential for providing comprehensive palliative care.	[27]
13	Potential for reduced human interaction	AI and robotics can improve care delivery, but over-relying on these technologies may reduce the essential human interaction that is crucial in palliative care. Patients nearing the end of life need caregivers' emotional and physical presence. AI and robotic interventions could decrease the time healthcare providers spend with patients, potentially impacting the emotional well-being of patients and their families, which is a key element of palliative care.	[31]
14	Society's readiness for intelligent machine proliferation	As society increasingly integrates AI-driven robotics across various sectors, addressing the ethical implications of this technological advancement is essential. The rise of AI and robotics brings challenges beyond technical capabilities, affecting societal impacts, job market dynamics, and the accessibility of advanced technology. The fusion of human intelligence with AI in robotics marks a paradigm shift, where machines evolve from mere tools to companions and cognitive extensions of human abilities. This transformation demands the creation of ethical guidelines to regulate AI system design and operations. Additionally, while AI-driven robotics enhances productivity and economic growth, it poses significant challenges, including legal and ethical concerns, regulatory frameworks, and societal readiness for the widespread deployment of intelligent machines. These issues must be addressed to ensure a responsible and sustainable integration of AI-driven robotics in society.	[32]

5. FUTURE RESEARCH DIRECTIONS

Below are the future research directions in AI-powered robotic technology for palliative care.

5.1. Development of personalized AI models for palliative care

AI holds significant promise in palliative care by enabling the development of highly personalized models that cater to each patient's unique needs, preferences, and disease progression. AI systems can analyze individual symptoms, treatment histories, and personal values to generate care recommendations that align with personalized goals by leveraging ML and big data analytics. Obaidur et al. [35] demonstrated that AI models emphasizing personalization have improved symptom management—particularly in relieving pain and anxiety—by more accurately predicting symptoms based on each patient's condition. Researchers are also exploring adaptive AI algorithms that continuously adjust based on patient feedback and health changes. This dynamic, responsive approach aims to enhance the patient experience by ensuring that care remains aligned with evolving needs.

5.2. Development of emotionally intelligent companion robots

Researchers are developing robots that recognize and respond to human emotions to provide companionship for palliative care patients and help reduce loneliness and depression. These robots use advanced AI algorithms to interpret facial expressions, speech patterns, and physiological signals, allowing them to engage in empathetic, human-like interactions. For example, developers have explored humanoid robots like Pepper for their potential to enhance social engagement among elderly individuals.

5.3. AI-driven pain assessment and management

AI systems that evaluate patients' facial expressions, vocalizations, and physiological data to determine their pain level could enhance the accuracy and promptness of pain management. These technologies enable healthcare providers to tailor interventions to each patient's needs. For instance, researchers have developed ML algorithms that detect pain in non-communicative patients by analyzing facial cues.

5.4. Interdisciplinary collaboration for ethical and human-centered AI development

A key trend in AI development for palliative care is the growing emphasis on interdisciplinary collaboration. As healthcare systems increasingly integrate AI and robotics—particularly in sensitive areas like palliative care—it becomes essential to involve experts from ethics, psychology, and sociology. These collaborations help ensure that AI technologies align with patients' values, preferences, and cultural contexts, reinforcing the human-centered nature of palliative care. A 2021 case study [116] urged AI developers, clinicians, and ethicists to collaboratively embed ethical frameworks into AI systems to address complex issues such as end-of-life decision-making and patient data privacy. In the future, researchers should focus on creating particular guidelines for the moral application of AI in palliative situations, together with highly sophisticated directives and do-not-resuscitate (DNR) orders.

5.5. AI-powered predictive analytics for patient deterioration

AI algorithms that forecast patient decline present promising opportunities for preventive therapies and better palliative care outcomes. These algorithms can predict clinical events, such as the start of sepsis, by evaluating EHRs and real-time patient data, allowing for earlier treatment. Predictive analytics is becoming more popular in symptom management because AI may identify early indicators of symptom worsening and trigger rapid treatments. By spotting trends in increasing symptoms, such as pain or nausea, AI-driven models improve the quality of care for patients with palliative cancer and enable timely modifications to treatment programs. Future research should improve these models' accuracy and broaden their use to a broader range of terminal situations.

5.6. Ethical frameworks for AI integration in palliative care

Creating thorough ethical standards for incorporating robotics and AI into palliative care is still crucial. Researchers should prioritize concerns such as algorithmic bias, data privacy, informed consent, and maintaining the human aspect of care.

5.7. Customization of robotic interfaces for patient interaction

Robotic interfaces can be more widely accepted and effective if customized to patients' preferences and cultural backgrounds. Developers can create more personalized and captivating interactions by altering a robot's language, appearance, and behavior to meet patient expectations. Essential insights for guiding these changes come from human-robot interaction and user experience design research.

5.8. Integration of AI robots with telemedicine platforms

AI-powered robots and telemedicine work together to enhance remote consultations, monitoring, and interventions in palliative care, where patients often have limited mobility. For instance, doctors can perform virtual visits with telepresence-enabled robots, significantly improving access to care.

5.9. Training and education for healthcare providers on AI utilization

Healthcare workers must be trained in AI and robotics to guarantee that these technologies are used competently and ethically in palliative care. Examples of practical approaches include developing courses that include ethical principles, technical skills, and patient communication techniques. The WHO stresses the importance of education in promoting the moral use of AI in healthcare.

5.10. Human-robot interaction (HRI) research for improved patient engagement

HRI needs to be enhanced as the use of robots in palliative care grows. Effective HRI requires the design of robots that adapt their actions and communication methods to the patient's emotional and physical conditions. Arunachalam [39] shows how robots that alter their speed, gestures, and tone of voice can give hospice patients a more compassionate experience, highlighting the potential for robots to be companions rather than merely instruments. Future research should enhance robots' ability to recognize and mimic human emotions to foster more natural and supportive relationships between patients and their families.

5.11. AI-powered tools for ethical end-of-life planning

AI-powered ethical end-of-life planning tools assist patients, families, and medical professionals make considerate, well-informed decisions consistent with their beliefs and preferences. These technologies help with advanced care planning, ethical problem resolution, and tailored decision-making support by evaluating health data and previous conversations. They ensure that legal and ethical standards are met, encourage communication, provide results models, and adapt treatment plans to changing medical circumstances. They also reduce the emotional burden of decision-making and consider cultural or religious sensitivities. These tools must prioritize privacy, transparency, and respect for individual autonomy to ensure ethical use. According to a 2020 study, AI can help patients make better decisions and enhance communication between patients, families, and clinicians. Future studies should enhance these tools' cultural competency to accommodate better diverse beliefs and behaviors related to death and dying [121].

6. CONCLUSIONS

Integrating AI into robotic technologies can revolutionize palliative care by enhancing the quality of life for patients with severe, life-limiting illnesses. Through its capabilities in real-time monitoring, personalized treatment recommendations, and human-robot interaction, AI-powered robots can provide critical support to patients and caregivers in delivering empathetic and efficient care. AI-driven robots assist with daily activities, monitor health parameters, and provide personalized interventions, reducing the physical workload of healthcare professionals while ensuring patients receive consistent and compassionate care. Additionally, the use of AI in robotic systems holds the possibility of meeting patients' particular emotional and psychological requirements in palliative care environments. AI-powered robots can be companions, lessen loneliness, and improve patients' general well-being by interacting with people in a human-like manner. In palliative care, when emotional support is just as crucial as physical comfort, this care component is especially vital.

However, despite the encouraging advantages, several obstacles remain to the complete utilization of AI-powered robotic technology in palliative care. Concerns about data gathering privacy, the proper degree of human-robot contact, and the possible emotional toll on patients and their families are just a few of the ethical issues that need to be addressed. Furthermore, training medical staff, modifying processes, and guaranteeing smooth communication between AI robots and current medical technology will cost money to integrate them into clinical practice. In conclusion, a multidisciplinary strategy is necessary to successfully apply AI-powered robotic technology, even though it has the potential to revolutionize palliative care. To manage the intricacies of this developing sector, cooperation between healthcare professionals, technologists, ethicists, and patients' relatives is crucial. More research, creativity, and communication are essential to overcome obstacles and guarantee that AI robotics can be successfully and morally included in palliative care procedures, ultimately improving patients' quality of life and the care experience for all parties concerned.

Conflicts Of Interest

The authors declare no conflict of interest.

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