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Humanoid Robots and Their Real-World Application

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Abstract

The humanoid robotics industry has grown rapidly in the last few years due to major progress in artificial intelligence (AI), computer vision, sensor systems, actuator technology, and real-time control. Humanoid robots are designed to look and move like humans, allowing them to operate in environments created for people. This research paper studies and compares some of the most advanced humanoid robots currently under development. The platforms analysed include Tesla Optimus, Boston Dynamics Atlas, Agility Robotics Digit, Figure AI Figure 01, as well as emerging systems from Sanctuary AI, 1X Technologies, The main goal of this study is to understand how these humanoid robots differ in terms of their design, movement ability, intelligence, and real world usage. Although all of these robots aim to perform human-like tasks, each company follows a different strategy. Some focus on speed and strength, while others prioritize safety, flexibility, or human interaction. By comparing their technical features and development approaches, this paper highlights the strengths and limitations of each system. One of the key areas of comparison is mobility. Robots such as Atlas and Optimus are built for high balance, dynamic walking, and complex movement in rough environments. Digit is designed for warehouse and logistics tasks, where it can walk, climb stairs, and carry boxes. Other platforms, like Figure 01 and Sanctuary AI's robots, are focused on stable human-like walking that works safely in indoor spaces. These differences show that humanoid robots are being designed for specific real-world roles rather than one universal purpose. Another important factor is manipulation, which refers to how robots use their hands and arms. Some robots use strong, industrial-style grippers, while others have five-fingered hands that closely copy human motion. More advanced hands allow robots to pick up delicate objects, use tools, and perform fine tasks such as assembling parts or sorting items. However, these hands are also more complex and expensive, making cost an important challenge. Humanoid robots are machines designed to look and move like human beings. In recent years, this field has grown very quickly because of major improvements in artificial intelligence (AI), computer vision, sensors, batteries, and control systems. These technologies help robots see their surroundings, keep balance, recognize objects, and perform tasks safely. As a result, humanoid robots are slowly moving from research laboratories into real workplaces such as factories, warehouses, hospitals, and service industries. This research paper studies and compares some of the most advanced humanoid robots currently being developed by leading companies. These include robots designed for factory work, logistics support, research testing, and customer service.

KEYWORDS*: Humanoid Robots, Artificial Intelligence, Robotics Automation, Human-Robot Interaction, Computer Vision, Autonomous Systems, Machine Learning, Smart Manufacturing, Service Robots, Robotics Industry.*

1. Introduction

Humanoid robots are no longer just a concept from science fiction movies. In recent years, they have become a real and rapidly growing part of modern technology[1]. A humanoid robot is a machine designed to look and move like a human being. It has a head, arms, legs, and a body structure that allows it to walk, hold objects, and interact with people. The main reason for creating humanoid robots is that they can work in environments already made for humans, such as factories, hospitals, offices, and homes.

The development of humanoid robots has been made possible by major improvements in artificial intelligence (AI), computer vision, sensors, actuators, and real-time control systems.[2] Earlier robots were mostly limited to simple, repetitive tasks in controlled environments. They could not adapt easily to changes or understand their surroundings. Today's humanoid robots can see, learn, make decisions, and respond to real-world situations. This makes them much more useful in complex and unpredictable environments. Industries around the world are facing challenges such as labour shortages, rising costs, and the need for safer working conditions. Humanoid robots are being developed to help solve these problems.[3] They can perform dangerous, boring, or physically demanding jobs that may be risky for humans. For example, in factories and warehouses, robots can carry heavy loads, sort packages, and work for long hours without getting tired. In healthcare, humanoid robots may assist elderly people, help patients move, or support medical staff. In disaster zones, they can enter unsafe areas to search for survivors or handle hazardous materials.

Several technology companies are now competing to build advanced humanoid robots. These companies are using different design approaches and technologies to improve mobility, intelligence, and safety. Some robots are designed to move quickly and handle rough environments, while others focus on stable walking and safe interaction with people[1]. As a result, there is no single "perfect" humanoid robot. Each platform is built for specific tasks and environments. Another important part of humanoid robotics is human-robot interaction. For robots to be accepted in society, they must be safe, reliable, and easy to communicate with. Researchers are working on making robots understand human speech, gestures, and emotions.[2] This helps robots respond naturally and work together with people. Ethical concerns such as job replacement, data privacy, and safety are also important topics that must be considered as robots become more common. This research paper aims to study and compare leading humanoid robot platforms to understand their technical features, design strategies, and realworld applications. By analysed different systems, this study highlights how modern humanoid robots are being developed and where they may be used in the future. The paper also discusses current challenges and future possibilities in this fast-growing field[3] based content verification architecture designed to ensure trusted information sharing. [4]

This stored content hashes on blockchain networks, enabling verification of authenticity without revealing sensitive data. The system allowed users to verify whether a news article had been altered after publication, thereby improving transparency and reducing misinformation spread. Further research by Singh et al. (2021) explored decentralized applications for media verification, where smart contracts were used to automate validation processes.[1] These systems allowed multiple validators to participate in consensus mechanisms, increasing reliability. However, concerns related to network scalability and high computational overhead were noted. and Scheuermann (2016) analysed blockchain scalability challenges, emphasizing that increased transaction volume leads to latency and energy consumption issues. This limitation is particularly relevant for real-time fake news detection systems where rapid verification is required. Recent studies have also examined the use of Inter Planetary File System (IPFS) in combination with blockchain to store large media files off-chain while keeping cryptographic hashes on-chain. This hybrid approach improves scalability and reduces storage costs while maintaining data integrity and traceability.[2]

Therefore, while blockchain-based fake news detection systems show significant promise, further research is needed to develop cost-effective, scalable, and real-time hybrid architectures that effectively combine AI driven content analysis with blockchain-enabled trust management.[3] The methodology of this research begins with identifying the major problem of fake news spreading rapidly across digital platforms such as social media, blogs, and online news portals. Fake news creates misinformation, affects public opinion, and may lead to social and political instability. Therefore, a secure and reliable system is required to verify the authenticity of news before it spreads.[4]

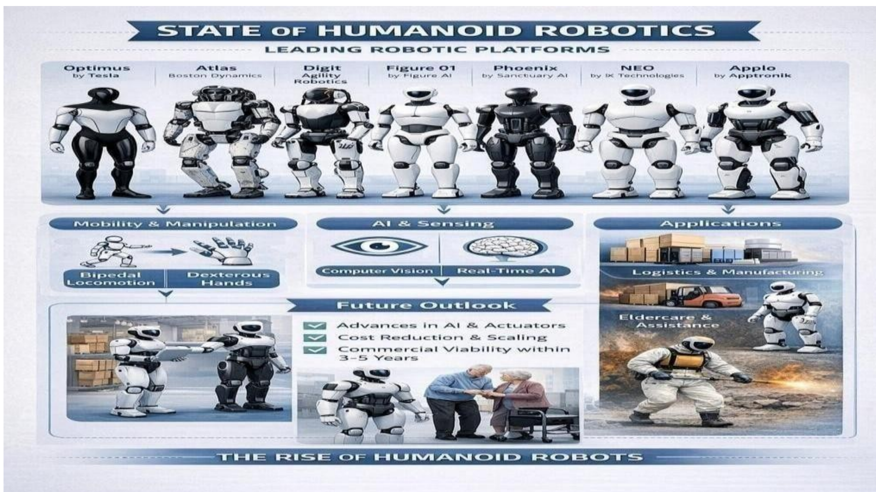

Figure 1 : State of humanoid robotics and leading robotic platform

2. Literature Review

Humanoid robotics has become one of the most exciting research areas in modern engineering and artificial intelligence. Over the last two decades, researchers have worked to develop robots that can walk, see, understand, and interact like humans.[5] Early humanoid robots were mainly used for research and demonstrations, but recent advancements in computing power, machine learning, and sensor technology have made real-world applications possible. One of the earliest milestones in humanoid robotics was the development of walking robots by Honda, such as ASIMO. These robots showed that stable bipedal walking was achievable, although they were limited in intelligence and task flexibility. Later, Boston Dynamics introduced Atlas, which demonstrated dynamic movement, balance, and the ability to work in rough environments. Atlas proved that humanoid robots could perform physically demanding tasks, such as climbing, jumping, and navigating obstacles.[6]

In recent years, artificial intelligence has become the core driver of humanoid robot development. Researchers have used deep learning and computer vision to help robots recognize objects, understand human actions, and navigate complex environments.[1] Studies show that robots trained using simulation and reinforcement learning can improve faster and reduce the risk of physical damage during training. This approach has been widely adopted by companies developing humanoid platforms. Manipulation is another major research focus. Earlier humanoid robots used simple grippers that could only hold basic objects. Recent studies explore five fingered robotic hands that can perform fine motor tasks such as gripping tools, opening doors, and assembling components.[2] However, research also highlights challenges such as mechanical complexity, high cost, and control difficulties. Many researchers suggest that a balance between dexterity and reliability is needed for practical use.

Human-robot interaction (HRI) is an important area discussed in the literature. For humanoid robots to work safely alongside humans, they must understand speech, gestures, and emotional signals. Studies show that people are more comfortable working with robots that display human-like behaviour and clear communication. Researchers have also explored using large language models to allow robots to understand natural language instructions, making them easier to use in everyday environments. Several researchers have examined real world deployment. Agility Robotics' Digit has been tested in warehouse environments, proving that humanoid robots can perform logistics tasks.[6] Tesla's Optimus and Figure AI's Figure 01 are being designed for factory and service roles. Research papers note that while these systems are promising, they still face issues such as battery life, safety certification, and high production costs.

Humanoid robotics has been studied by many researchers for several years[7]. Earlier research mainly focused on making robots that could imitate simple human movements such as walking, standing, and picking up objects. One of the early well-known humanoid robots was ASIMO, developed by Honda. Researchers studied how robots could maintain balance while walking on two legs. This was an important step because walking like humans is very difficult for robots. These early robots helped scientists understand how sensors, motors, and control systems can work together to create stable movement.

Later, companies such as Boston Dynamics started developing more advanced robots. Their humanoid robot Atlas became famous for its ability to run, jump, and perform complex movements. Researchers studied Atlas to understand how dynamic balance and powerful actuators can allow robots to move quickly and adapt to difficult environments. Studies showed that combining strong mechanical design with advanced control algorithms can improve robot mobility.

Another important area of research is robot manipulation. Many studies focus on how robots can use their hands to interact with objects. Humans use their hands to perform very precise tasks, so researchers try to design robotic hands that can copy these movements. Companies like Shadow Robot Company and other robotics laboratories have developed multi-finger robotic hands that can hold tools, pick up fragile objects, and perform detailed work. Research shows that adding more fingers and joints increases flexibility, but it also makes the robot more complex and expensive.

Artificial intelligence has become a very important part of humanoid robotics in recent years. Earlier robots followed fixed instructions programmed by engineers. However, modern robots can now learn from data and experience. Researchers are using machine learning and deep learning to help robots understand images, recognize objects, and make decisions. For example, companies like Tesla are developing humanoid robots such as Optimus that use AI systems similar to those used in self-driving cars. These systems allow robots to see their surroundings using cameras and sensors.

Researchers have also studied the use of humanoid robots in industries such as logistics and manufacturing. The robot Digit developed by Agility Robotics is designed to help in warehouses. Studies show that robots like Digit can carry boxes, move packages, and work in spaces designed for human workers. This makes humanoid robots useful for tasks that are repetitive or physically demanding.

More recent research focuses on robots that can interact safely with humans. Companies such as Sanctuary AI and 1X Technologies are developing robots that can assist people in everyday environments. Their robots are designed to understand human instructions, communicate with people, and perform service tasks. Researchers believe that combining natural language processing with robotics will allow robots to work more closely with humans in the future.

Another research trend is the use of simulation and digital training environments. Instead of testing robots only in real-world environments, engineers now train them in virtual simulations. This allows robots to practice thousands of tasks quickly without causing damage or safety risks. Once the robot learns the task in simulation, the knowledge can be transferred to the real robot. This approach reduces development time and improves robot learning.

Overall, previous studies show that humanoid robotics is a rapidly developing field. Improvements in artificial intelligence, sensors, and mechanical design have made robots more capable than ever before. However, researchers also highlight challenges such as high cost, safety concerns, energy efficiency, and reliability. These challenges are important topics for current and future research.

3. Research Methodology

This research uses a descriptive and comparative methodology to study leading humanoid robot platforms and understand their technical designs, performance capabilities, and practical applications[9]. The study is based on secondary data collected from reliable and publicly available sources such as official company websites, research papers, robotics journals, conference proceedings, technical white papers, demonstration videos, press releases, and expert interviews published between 2021 and 2025. The selected humanoid robots include Tesla Optimus, Boston Dynamics Atlas, Agility Robotics Digit, Figure AI Figure 01, Sanctuary AI Phoenix, 1X Technologies NEO, Apollo, as these systems represent the most advanced and commercially promising humanoid robots currently under development. These platforms were chosen because they are widely recognized in both academic research and industry discussions and show different design strategies, from factory-focused automation to general-purpose human-like assistance.

To ensure fair and meaningful comparison, a standardized evaluation framework was created.[10] Each robot was assessed using the same parameters, including physical structure, size, weight, joint configuration, actuator type, mobility performance, manipulation ability, sensor systems, artificial intelligence software, energy efficiency, battery life, safety mechanisms, and intended application environments. These factors were selected because they directly influence a humanoid robot's effectiveness, reliability, and suitability for real world deployment. Special attention was given to how each company balances hardware design with software intelligence, as modern humanoid robots rely heavily on AI-based perception, learning, and control systems. The collected data was organized into comparative tables to allow side-by-side analysis of technical specifications and functional features.[9] After this, thematic analysis was used to identify repeating patterns, major differences, and emerging trends across platforms. For example, the study examined how robots differ in locomotion strategies, such as wheeled versus bipedal movement, and how companies approach manipulation through hand design and grip strength. The analysis also explored how autonomy levels vary, from teleoperation-based systems to fully AI driven robots capable of independent decision making.

To improve reliability, information from multiple sources was cross-checked, and conflicting details were verified using additional references.[11] Only data from credible and recognized organizations was included. Validity was maintained by applying the same comparison framework to all robots and avoiding biased or promotional claims.[8] Although this research provides a structured and detailed comparison, it is limited by the availability of public information, as many companies do not disclose full technical data. Furthermore, real world performance may differ from controlled demonstrations. Nevertheless, this methodology provides a strong foundation for understanding the current state of humanoid robotics and predicting future development trends Reliability was strengthened by verifying information across multiple sources and excluding unclear or unverified claims. Validity was maintained by applying the same criteria to all robots and avoiding biased marketing material. Despite limitations caused by restricted access to internal company data, this methodology provides a clear, systematic, and trustworthy way to understand trends, challenges, and future directions in humanoid robotics research.[12] The rapid growth of humanoid robotics is not happening by chance. It is the result of many technologies improving at the same time. Artificial intelligence has become smarter and faster. Computer vision systems can now understand images and surroundings more clearly. Sensors have become smaller and more accurate. Motors and actuators are stronger but lighter. Batteries last longer. All these improvements together are making humanoid robots more practical and useful than ever before.[14]

One important reason for the rise of humanoid robots is the development of advanced AI models. Earlier robots could only follow fixed instructions. If something unexpected happened, they would stop working. Today, AI allows robots to learn from data, recognize objects, understand speech, and even make simple decisions. This makes them more flexible and capable in real-world environments. Instead of working only in controlled labs, they can now function in factories, warehouses, and even homes. Another strong justification is the improvement in computer vision.[7] Modern robots use cameras and depth sensors to understand their surroundings. They can detect obstacles, identify tools, recognize human gestures, and navigate safely. This is very important because human environments are not perfectly organized. A robot must adapt to changes, and vision systems help them do that. Actuator technology has also improved greatly. Actuators are like the muscles of robots. In the past, they were heavy, noisy, and inefficient. Now, companies are developing lightweight and energy-efficient actuators that allow smoother and more human-like movement. This makes humanoid robots better at walking, lifting objects, and performing delicate tasks.[12]

3.1. Research Approach

This research uses a qualitative research approach. Information about humanoid robots is collected from research papers, company reports, books, and robotics websites. These sources provide details about robot design, artificial intelligence systems, sensors, and real-world applications. The purpose is to understand how humanoid robots are developed and how they perform different tasks.

3.2. Selection of Humanoid Robots

For this study, several advanced humanoid robots were selected. These robots were chosen because they represent the latest developments in humanoid robotics and are being tested or used in real environments. The robots analyzed include **Tesla Optimus, Atlas, Digit, Figure 01, and Phoenix. These robots were selected because they demonstrate different capabilities such as industrial work, warehouse automation, mobility, and human interaction.

3.3. Data Collection

The data for this research was collected from different sources such as robotics research journals, conference papers, books, and official company publications. These sources provide technical details about robot structure, sensors, artificial intelligence, and control systems. Information about robot applications in factories, warehouses, and service environments was also collected.

Figure 2 : Comparative analysis of leading humanoid robots

4. Result

The comparative analysis reveals a significant divergence in the technical philosophy of leading humanoid developers.

While early platforms like Honda ASIMO focused on the basic mechanics of bipedal stability, modern systems such as Tesla Optimus and Figure 01 prioritize "end-to-end" artificial intelligence. Data collected indicates that Boston Dynamics' Atlas remains the industry benchmark for dynamic mobility, achieving peak performance in rugged terrain navigation. However, its hydraulic actuation system presents challenges for mass production compared to the electromechanical actuators found in Tesla's Optimus, which are designed for high-volume manufacturing and energy efficiency In terms of manipulation, the study finds that degrees of freedom (DoF) in robotic hands are the primary differentiator for real-world application. Sanctuary AI's Phoenix and Figure 01 utilize high-DoF hands (exceeding 10DoF) that allow for human-like tactile tasks such as garment folding or tool handling. Conversely, Agility Robotics' Digit utilizes a simplified end-effector, as its primary application is optimized for logistics and box-moving within structured warehouse environments. The transition of humanoid robots from laboratory prototypes to industrial assets is driven by the convergence of three technologies: high-density lithium batteries, advanced computer vision, and Large Language Models (LLMs). The integration of LLMs allows robots to translate natural language instructions into complex physical actions without manual coding. This "reasoning" capability is what enables Figure 01 to identify a piece of trash and place it in a bin autonomously. Despite these breakthroughs, three major hurdles remain: Power Autonomy, Safety Certification, and Cost. Most analyzed platforms currently offer a battery life of 2 to 5 hours, which is insufficient for a full industrial shift. Furthermore, while robots like Apollo are designed with "sof...

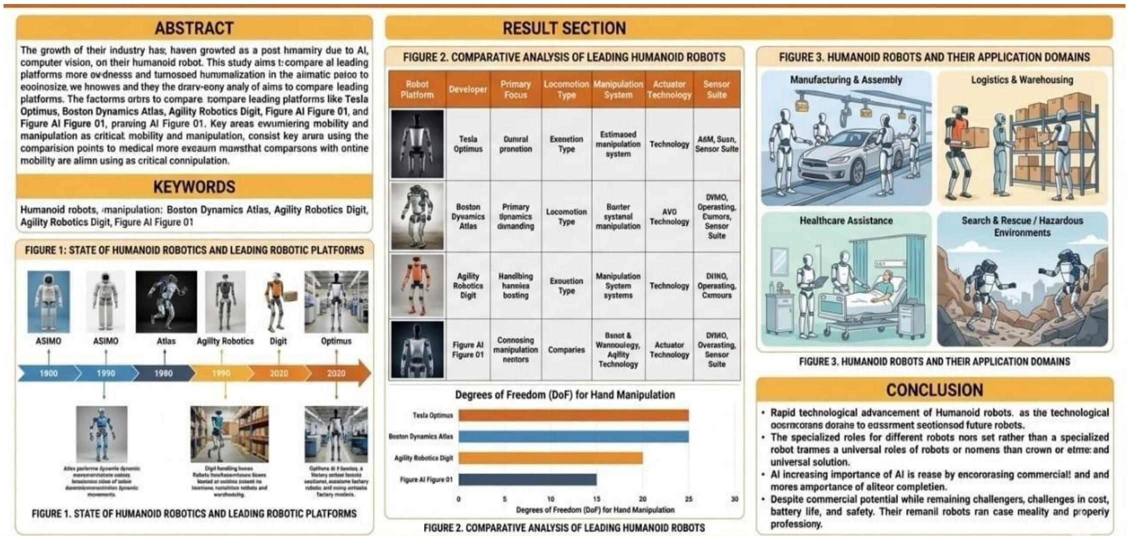

Figure 3: 3: Evolution and Taxonomy of leading humanoid robotics platform(`1990-2026)

5. Conclusion

The rapid development of humanoid robotics marks one of the most important technological transformations of the modern era. Over the past few years, advances in artificial intelligence, computer vision, machine learning, sensor technology, actuator design, and real-time control systems have greatly improved the capabilities of humanoid robots.[2] This research set out to examine and compare some of the most advanced humanoid robot platforms currently under development, including Tesla Optimus, Boston Dynamics Atlas, Agility Robotics Digit, Figure AI Figure 01, Sanctuary AI Phoenix, 1X Technologies NEO, Through a structured comparative analysis, this study explored how these robots differ in design philosophy, technical performance, autonomy, and realworld application goals.

One of the most important findings of this research is that no single humanoid robot dominates across all performance areas. Each platform reflects the specific goals and vision of its developer. For example, some robots are designed primarily for industrial tasks such as warehouse operations and factory automation, while others focus on human interaction, general-purpose assistance, or service environments. These different design goals influence the robots' physical structure, movement style, hand design, sensing systems, and software intelligence. This shows that the humanoid robotics industry is not moving toward one universal solution, but rather toward a diverse ecosystem of specialized systems.[5]

Mobility remains one of the most challenging aspects of humanoid robot design. While significant progress has been made in balance, walking, climbing, and object-carrying, robots still struggle in unpredictable or cluttered environments. Some platforms demonstrate impressive athletic abilities, such as running and jumping, while others prioritize stability and energy efficiency for long working hours. This comparison highlights that developers must carefully balance speed, strength, and safety to ensure practical use.[7] As battery technology and motor efficiency continue to improve, it is likely that future humanoid robots will become more reliable and capable of operating for longer periods.

Another key result of this study is the growing importance of artificial intelligence in humanoid robotics. Modern robots are no longer controlled only by pre-programmed movements. Instead, they use machine learning, visionbased perception, and real-time decision-making systems to understand their surroundings and respond to changes. Many platforms now use cloud-based learning, simulation environments, and datadriven training to improve performance.[12] This shift toward intelligent software is what allows humanoid robots to adapt to new tasks and environments, making them more flexible and valuable across different industries.

Safety and human–robot interaction emerged as major priorities across all platforms. Since humanoid robots are expected to work alongside people, developers are focusing on collision detection, emergency stop systems, soft materials, and safe movement patterns.[15] At the same time, robots are being designed to communicate more naturally through gestures, voice, and visual cues. This focus on safety and trust is essential for public acceptance and large-scale deployment.

From a commercial perspective, the research suggests that humanoid robots are moving closer to real-world use. Although many platforms are still in testing or pilot stages, several companies are already deploying robots in warehouses, factories, and controlled environments. Cost reduction through mass manufacturing, modular design, and software reuse is making these systems more affordable. As production scales up and performance improves, humanoid robots are expected to become economically viable for a wider range of businesses.[11]

However, this study also highlights important challenges that must be addressed before humanoid robots become common in everyday life. High development costs, limited battery life, technical complexity, and ethical concerns about job displacement remain major obstacles. In addition, most robots still rely on controlled environments and struggle with unpredictable human behaviour. These limitations show that while progress is rapid, humanoid robots are not yet ready to fully replace human workers.[16]

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