

Designing Intelligent Agents for Effective Collaboration with Human in Complex Environment

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Abstract

An intelligent agent is a self-governing system that can take action to accomplish its goals based on how it perceives its surroundings. This paper introduces a newly designed humanoid robot that demonstrates significant advancements in performance, reliability, durability, energy efficiency, and environmental sustainability. The design emphasizes a bio-inspired musculoskeletal system, enabling natural and flexible motion while improving operational lifespan. A self-repair system is integrated to allow the robot to address minor damages autonomously, enhancing its robustness and reducing downtime. The relationship between precise actuator movements, advanced perception techniques, and optimal sensor selection is analyzed to ensure accurate environmental interactions. A cognitive AI-system is embedded, enabling adaptive learning and improved decision-making in dynamic scenarios. The robot's capabilities are further enhanced by its bio-inspired actuation, which combines efficiency with smooth, natural motion. This work explores the application of humanoid agents in diverse fields, including medical care, industrial production, vocational education and training, public services, and customer relations. The integrated approach outlined in this paper positions humanoid robots as versatile, efficient, and sustainable agents in complex human-centered environments.

Keywords: Intelligent agent, humanoid robot, bio-inspired design, cognitive AI system, human-robot collaboration

INTRODUCTION

An intelligent agent is an autonomous system that acts based on its perception of the environment and is capable of performing actions to achieve objectives. It is designed to work with source initiative, whereby it can satisfy goals via information collection using sensors. This strategy focuses on improving the performance of the agent in order to handle the changes.

Complex environment in artificial intelligence relates to a system that is highly dynamic, full of a large number of unpredictable changes and interactions that are difficult to be understood or explained by the agent. Such environments include actual real-life scenarios, rather than simple warehouses or factories, and involve unpredictable human interactions.

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A humanoid agent is a mobile entity that can be interfaced directly with a human through integration and thus is able to perform functions in a manner as a human being would do. These agents can accomplish tasks that call for human-like manipulatory and locomotive capabilities because most of them include principal parts such as human-like heads, arms, and legs. Mobile robots can detect the environment, and possess more efficient sensory systems and tools on demand to operate efficient actuator systems in their environment. In more

detail, humanoid agents are affected by issues related to real social interactions, such as dynamic constraints of newly occurred interactions, and flexibility of interaction patterns. It is associated with artificial intelligence-rich algorithms and mechanisms and is capable of raising the efficiency of this design in proportionate ways.

The objective of this research is to design an intelligent agent for effective collaboration with humans in a complex environment. This work aims to identify necessary learning mechanisms and factors for effective collaboration with humans and agents.

RELATED WORKS

Recently, a company in the UK named "Ameca" released a humanoid agent. This agent is able to express and display emotional reactions on the face. Unfortunately, the robot cannot move. It is controlled by humans and information about this agent is limited [1].

Alter-3 does not exactly mimic humans; rather, humans mimic Alter-3. Contact with Alter-3 reduces humans' sense of movement [2].

Humanoid robots represent an emerging and promising robotics application field that requires humanoid agents to have reliable human motion skills to be necessary and economically viable. This work focuses on the mechatronic components of new humanoid robots, as well as real-time control systems [3].

Humanoid robotics is not a well-defined and renowned topic at present, but it has underlying motivations which can drive collaboration in other fields [4]. Currently, there is almost no knowledge of the biological nature of humanoids and far fewer simple models of this. The biological processes are partially understood, and the full picture has not yet been revealed [5].

Other robots such as Ameca can perform optimal actions using reinforcement learning and complete other tasks in a similar manner using learning mechanisms, as well as incentives [6].

Categories of service robots, namely 'Humanoid robots', are employed in activities that call for human-robot interface, including health care, teaching, and customer relations. Since these robots look like humans or mimic human expressions, social interactions become natural and acceptable. However, it is seen that conventional robots can only achieve this through intermediate devices or control systems [7].

Considering the above issues, we design a new intelligent agent in this paper that overcomes the limitations already discussed.

METHODOLOGY

A novel methodology for designing intelligent agents is shown in Figure 1. The different components are explained as follows:

- *Power System:* In our design of intelligent agents, we propose solid-state battery technology. This technology is different from lithium-ion batteries, which employ a flammable liquid electrolyte. Instead, solid-state batteries utilize a solid electrolyte. Our model includes an energy harvesting system. This system involves a technique for capturing and utilizing environmental energy as electrical power to enhance or power the agents' original battery source.
- *Exoskeleton:* The Exoskeleton part consists of a bio-inspired joint system and a carbon nanotube-reinforced structure. Bio-inspired joints very closely imitate the joint systems of a human body. These joints are hinged, pivoted, and ball-and-socket. They include such elements, as well as flexible, elastic materials or multilayer structures, imitating the action of ligaments, tendons, and muscles. This framework is made of carbon nanotube (CNT) composites. Carbon nanotubes are stronger than regular structural materials such as steel, but at the same time, their lighter weight

endows the agent with structural robustness capable of encapsulating high-pressure functions. CNT design allows the agent to bear pressure and dampen vibration, while also providing balance and stability during operations such as high-speed movements or weightlifting.

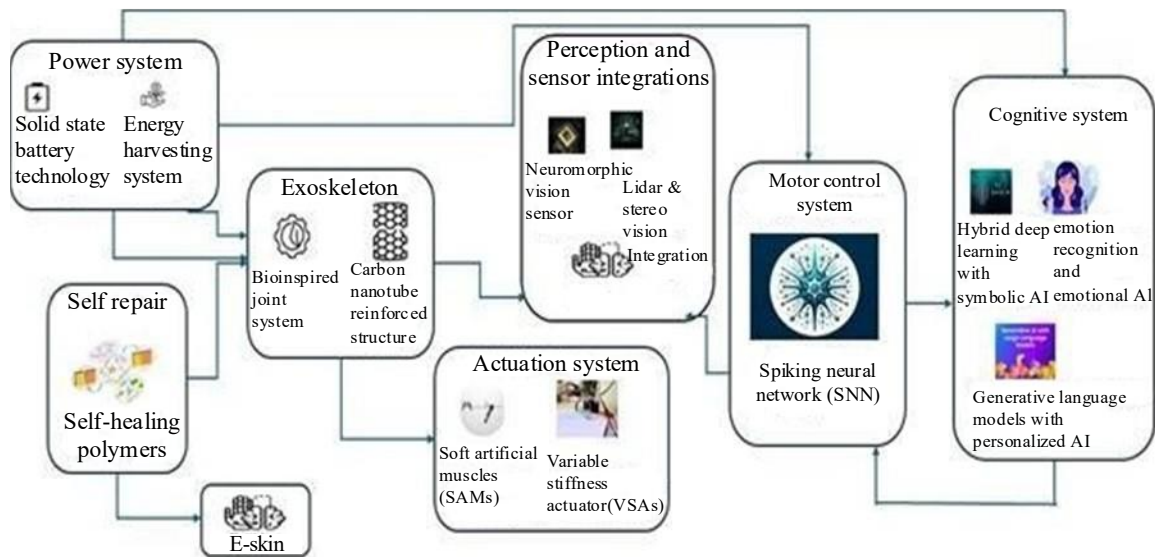


Figure 1. Intelligent agent for effective collaboration with human.

- *Self-Repair:* Auto-recovery or self-repair is defined as the agent's ability to repair itself without requiring intervention from its constituents. In our system, auto-recovery is done using self-healing polymers. Self-healing polymers refer to synthetic materials that are capable of reversing their structure and properties when they are damaged. These polymers are capable of responding to such damage (including cuts or scratches), and these can be designed for fully or partially synthetic healing.
- *E-Skin:* Electronic Skin (E-Skin) is an artificial skin made of synthetic fibers. It mimics the characteristics of human skin and is capable of improving the perception of the environment by humanoid agents. This technology is compatible with pressure, humidity, temperature, and even chemical transformation measurements. It also allows the integration of highly adaptable sensors that enable agents to more closely replicate the roles of their human counterparts. Robotic skin helps agents perform fine movements that require interaction with people and respond to the surroundings in real time. The advancements in the construction of e-skin materials, such as self-healing polymers, envisage enhanced durability and flexibility of the agent, in addition to performing skin-sensitive tasks.
- *Actuation System:* Humanoid agents need an actuation system that can mimic human movements and also function like human body parts. Actuators include electric motors, pneumatic or hydraulic muscles for the purpose of driving agent joints and organs. Most actuators are controlled by complex algorithms that interpret the sensory data and enable proper movement and complex actions, encompassing tasks such as walking, grasping, manipulating objects, and interacting with the environment. Proper design of the actuation system is of paramount importance for achieving efficient actuation, stability, and force utilization. It also improves the general utility of the agent in diverse environments where it may be required. The actuation system can be made of Soft Artificial Muscles (SAM) and Variable Stiffness Actuators (VSA).

To mimic human muscle movements, SAMs are designed. In most cases, these actuators are made of soft materials. These can alter their shape or size in response to various signals, for instance, electrical stimulation, heat, or fluid power. There are different ways through which SAMs function. These include pneumatic structures inflated by air; electrically active polymers that change their shape due to an electric field; and shape memory alloys that regain their predetermined shape after being heated. This makes SAMs smooth and offers lively speed.

A VSA is essentially an actuator that can change the stiffness of an agent's joints and limbs. Just as human muscles flex and relax, this feature provides a humanoid agent with an advantage. VSAs work by being provided with springs, gears, and dampers to change their mechanical characteristics. Actuators are able to transform from rigid to flexible modes by increasing their stiffness, making it possible for an agent to optimize itself for different tasks and environments.

- *Perception and Sensor Integration:* Perception and sensor integration in a humanoid agent involves capturing, processing, and fusing sensory signals in order to make sense of the environment. It includes neuromorphic vision sensors, Light Detection and Ranging (LiDAR), and Stereo Vision. The neuromorphic vision sensor utilized has functionalities similar to the human vision system. Though most may capture frames at intervals similar to a standard camera, such sensors can detect faster changes in the scene as they happen (event-based) and focus only on the necessary region displaying the motion or change. A neuromorphic vision sensor, for example, located in a humanoid agent, is more effective and natural for motion and change identification in a variety of applications, thus enabling a fast response to the target or to the changing environment. For example, it can perceive a moving object or other agents when placed in a constantly changing environment. LiDAR technology employs light to define the proximity of a sensor to its environment. LiDAR also measures the time taken to fire laser pulses. The most impressive aspect of LiDAR is its ability to construct entirely three-dimensional maps of its environment. This technology is useful for an agent wishing to understand the geometric layout of an area. LiDAR aids in the detection of objects from various distances, thus preventing human errors. Stereo vision separates two cameras to create a binocular appearance, and by comparing images from the left and right cameras, an agent can estimate depth and measure distance. Thus, the integration of stereo vision with other sensors, such as LiDAR, enhances the perception of a human agent.
- *Motor Control System:* The motor control system deals with the coordination of the motion and timeliness of the humanoid agent and features the emulation of human-like movements. This system serves as an actuator, sensor, and feedback system for an agent's joints, limbs, and general human movement control. This system enables balance control. In walking, and to a lesser extent in running or climbing, fine control of the motor neuron supply is essential for detailed muscle control. The main component of this system is Spiking Neural Networks (SNNs). SNNs function by processing input through small energy spikes, similar to a biological brain. SNNs, as part of the sensory input and motor output systems of humanoids, provide a means for rendering high-level, real-time decisions rapidly. Agents can significantly respond to sensory inputs and adjust behavior rapidly because SNNs offer the advantage of real-time signal processing capability. This enables humanoids to perform operations naturally and in a manner that mimics flexible human operation.
- *Cognitive System:* The humanoid agents possess distinct, privileged, and enhanced selection, learning, and problem-solving abilities within their cognitive systems. Their capabilities include perceiving, understanding, and acting autonomously. Cognitive systems integrate various types of data crucial for an agent's thinking, performing, and acting, including sensory and contextual data. This framework is essential for humanoid agents to generate coherent conversation based on learned events. The system includes symbolic AI, hybrid deep learning, emotion recognition and emotional AI, generalized language models, and personalized AI. These systems offer superhuman capabilities in pattern recognition, married with the logic of symbolic AI, to compare objects effectively. Therefore, this technique enables such humanoid agents to perform far more powerful cognitive functions. Deep learning techniques can help an agent differentiate items. Symbolic AI is useful for enabling perception and interaction between two or more objects in specific ways. It predisposes interactions and brings responses closer to human-like understanding. Emotion recognition and emotional AI also enable them to influence, control, and provide feedback on emotions based on facial and vocal semiotics, kinesics, and other parameters. Symbols help explain feelings such as happiness, grief, or anger, or a person's temperament over a given period, resembling the state of the human brain. Emotional AI is designed to make automatons appear human-like by enabling emotional responses and adjusting

tones and movements. This makes them easier and more engaging for users to interact with. Generative language models, together with personalized Artificial Intelligence, are sophisticated language models that facilitate humanoid entities in engaging in natural and novel ways of speaking. These models generate AI that mimics human responses to such inputs. Adaptive AI learns language patterns and preferences, functioning in a manner that directly responds to them. This enables humanoid agents to engage in useful, meaningful conversations, serving as assistants or companions.

COMPARISON WITH OTHERS

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Other robots, such as Ameca, employ conventional motors in which flexibility is somewhat restricted. SAMs and VSAs imitate muscle tissue, allowing for more realistic, human-like motion, which in turn enables robots with humanoid or AI capabilities to perform to their highest potential under human-like conditions. They can operate under different pressure and motion ranges with great facility [8].

SNNs aim to better emulate the information processing functions of human brains. They achieve this by enabling neurons to transmit information with single spikes. This makes SNNs one of the best paradigms for brain-inspired computing systems, especially in neuromorphic device architectures where biological inspiration is stringent [9]. Event-driven computations are a hallmark of SNNs; neurons only discharge when a signal reaches a particular level of intensity. This leads to orders of magnitude less power consumption than the continuous computations of CNNs. This feature makes SNNs suitable for energy-restricted applications since they require less electricity for processing. Unlike CNNs, which have high computational requirements [10], SNNs are capable of overcoming the barriers set by wearable devices and edge AI.

Neuromorphic vision sensors typically have a much greater dynamic range of 120 dB or more compared to conventional cameras. These cameras can easily record features in both very bright and very dark regions of an image simultaneously. This makes them ideal for applications involving difficult lighting conditions, such as self-driving automobiles, surveillance, and expansive robots [11].

LiDAR technology offers accurate depth measurements. This is particularly useful in environments where stereo vision can provide dense depth maps at short range with high spatial accuracy. The two systems combine to yield more accurate and detailed depth information, which in turn enhances object obstacle detection.

In soft robotics, where tissue-like and gentle motion is preferred, e-skin offers tactile feedback that is challenging for conventional sensors to provide. The integration of e-skin in soft robots enhances sensitivity, allowing safe and effective interaction with humans and the environment [12].

Symbolic Knowledge AI can provide systematic knowledge representation and reasoning abilities, imparting new tasks to robots more quickly due to their available knowledge. This is especially useful when data is scarce or costly to acquire because it can modify that state rapidly [13].

Emotionally intelligent robots are able to both feel and accurately interpret emotions in others through facial expressions, voice, and gestures. This feature provides robots with the capacity to modify their responses depending on whether the human is happy, sad, angry, and so on. The end product is smoother, more authentic, and genuinely worded communication. Emotional AI also enhances interaction, providing robots with human-like touch, and improving user interaction.

Special attention is paid to energy efficiency through innovative technologies in the described exoskeleton system. Energy harvesters capture stray energy, thus minimizing the requirement for

supplementary energy. Compared to liquid electrolyte batteries, solid-state batteries provide greater energy and charge efficiency. Self-healing materials are employed where low levels of maintenance are expected. Joint design is carried out with reference to human experience. Neuromorphic sensors and spiking neural networks optimize energy demands for sensing and processing. Enhanced by generative language models and deep learning systems, additional AI is designed to provide efficiencies derived from being tailored to minimize computational load.

The illustrated methodology applies modern technologies to achieve lightweight and flexible designs. Solid-state batteries and the use of a carbon nanotube-reinforced structure result in weight reduction. Soft artificial muscles (SAMs) and variable stiffness actuators (VSAs) offer human-like convenience and versatility. This methodology leads to a slim and adaptable external frame that is perfect for mimicking humanoid robotics, which would eventually increase its versatility and effectiveness in various scenarios.

In more detail, self-repairing polymers can recover from damage and regain their properties, while others require human intervention. This system is ideal for applications that are difficult or costly to maintain.

CONCLUSIONS

This paper presents an innovative humanoid robot design integrating cutting-edge technologies to enhance structure, mobility, interaction, energy efficiency, and stability. The proposed design surpasses existing humanoid robots, such as Ameca, by leveraging bio-inspired musculoskeletal systems, advanced actuation mechanisms, self-repairing materials, and cognitive AI systems. These features collectively enable the robot to exhibit natural, flexible motion, extended operational lifespan, and improved decision-making capabilities, making it suitable for dynamic and complex environments.

The integration of neuromorphic sensors, solid-state batteries, and energy-harvesting systems ensures low energy consumption and environmental sustainability. Additionally, features like e-skin and emotion-aware AI enhance human-like interactions and adaptability in diverse fields such as healthcare, education, public services, and industrial operations.

Future work will focus on implementing and validating the proposed methodologies through experimental studies and real-world applications to substantiate the theoretical advancements presented. This research contributes a robust foundation for developing intelligent humanoid agents that can effectively collaborate with humans in complex environments, paving the way for further innovation in robotics and artificial intelligence.

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