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Research Article

Humanoid Robot: A Review of the Architecture, Applications and Future Trend

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Abstract: With the advancement in the area of robotics, exoskeleton technology has come a long way since its beginnings in the late 60's. Researchers over the world have developed their own exoskeleton prototypes and some of the well known exoskeleton includes the BLEEX, MIT exoskeleton, HAL, LOPES, ALEX and many more. Although technologies have since improved from the 60's, challenges still exist in exoskeleton design. In this study, we are going to review different exoskeleton technologies as well as its role in the area of rehabilitation. This purpose in rehabilitation is promising, based on countless of researches which have been done.

Keywords: Body, humanoid robot, robot, robot architecture and robotic applications

INTRODUCTION

A humanoid robot is generally defined as a programmable machine which can imitate the actions as well as the appearance of human (Graefe and Bischoff, 2003). A humanoid robot has two main functions, which are the ability in acquiring information from its surrounding and the ability to carry out physical work, such as moving or manipulating objects. After years of research and study, the available humanoid robots nowadays have different sizes, weights and heights which related to their application. Generally, humanoid robots act like a human, where they can express their emotion by moving their eyelids and mouths. In addition, they have hands and legs so they can carry out different tasks like human and they even have the ability to learn new things by using the sensors and other technologies such artificial intelligence. In short, humanoid robot is actually a robot which equipped with sensors to perceive their environment and its effectors to execute an action.

This review study has been divided into three main sections: the architecture, applications and future trend. The first section discusses the technology or system applied to the humanoid robot. There are four main criterions of the humanoid robot which are the facial expressive robot head, robot hand, robot locomotion and robot learning behaviour. The second section discusses how the humanoid robots are being applied in different fields such as home application, entertainment, healthcare, sport, space exploration, construction, industry and education. The final section outlines the future trend of the humanoid robot.

ARCHITECTURE

A humanoid robot is a machine which is like a duplication of human being. A humanoid robot should look like a human and act like a human. With the advancement of the technology, nowadays, the appearance and characteristic of the humanoid robot is becoming more and more similar to human. The following subsections discusses about the technology is being invented to make the humanoid robot looks like a human in term of the facial expressive robot head, robot hand, robot locomotion and robot learning behavior.

Facial expressive robot head: The research on humanoid robot is focusing on the interaction between human and robot. In order for a humanoid robot to act just like a human, the communication ability is always the important one. In our daily human-human communication, we always communicate to each other through facial expression, gestures with arms and hands, speech and other body language. These actions are carried out by human easily and was started to practice since early childhood. In human-robot communication, we wish the robot can perform like what we are performing. Therefore, some researchers started to design the humanoid robot of mimicking human behavior.

One of the important characteristic of human is the ability to express emotions in face. In the daily human communication, expression determines the personal characteristic and it improves communication effectiveness. We always hope to communicate with robots in a similar way like humans. Therefore, researchers have developed the facial expressive robotic

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head systems e.g., Character Robot Face (CRF) (Fukuda *et al*., 2004). In Japan, a human-like head robot named WE3RV was developed (Miwa *et al*., 2001). The emotion of human such as happiness and anger is defined and loaded into the robot. When the robot has detected the external stimuli by using sensors, the information will be converted and the robot will express the emotion by moving the different parts on the face including eyebrows, ears, eyelids, lips and mouth like human. For example, a robot called Kismet developed in Cambridge which can perform variety of proto-social responses using the technology of CCD camera and able to exhibit expressions just like human (Breazeal and Scassellati, 1999). The biggest challenge is that the expression coverage of a humanoid robot is not covered enough. For example, the happiness of human can be further divided into many different levels and each level of happiness has a unique expression. The technology of human-like head robot continues to advance so that the expression coverage will be similar to human.

Gazing is also a very important action in human-human communication. It is used by a speaker to communicate with his/her listener as gaze pattern which can communicate a speaker's attitude. In order to show respect when talking, eye contact is a rude or dominant signal where people will look at other. Therefore, researchers also take into consideration of implement the gazing ability in the robot. For example, the researcher has implemented a gaze and gesture algorithm for Honda's humanoid robot, ASIMO (Mutlu *et al*., 2006). So the ASIMO has the ability to gaze and show hand gestures to people and it is considered as a story-telling robot. Gaze control of a humanoid robot involves the fixation point detection with the coordination of head-eye movements (Gu and Su, 2006). A camera is used as the eyes of the humanoid robot. The head of the robot will move according to the detected object.

Robot hand: Hand is one of the important organs of a human in carrying out daily task. Without hands, human will not complete a task in an easy way. This is also applied to a humanoid robot, so hands are equipped to a humanoid robot. The human hand is a complex system which is very difficult to be replicated in its performance and features. The important characteristics of the artificial hand that replicates human hand for a humanoid robot are the weight, dimensions, minimum number of fingers, essential degrees of freedom (df) of the fingers and others (Zollo *et al*., 2007). The researches have carried out extensively in developing the anthropomorphic artificial hand based on the important characteristics that gives the essential function to the hand which usually driven by DC motors.

Human's hand can perform different type of tasks with fingers. Human can control fingers easily because they have been awarded the skill since they were born. However, for a humanoid robot, it is very difficult to execute the action in order to carry out tasks such as stably pinching paper or needle with finger tips. A robot with four fingers, each having three degrees of freedom, has been developed for high performance remote manipulation. However, the manipulation technique is still in the development stage. In Japan, researcher has made the robot's hand to pinch up the paper. They have added additional degrees of freedom of independent motion to the terminal fingers and the degrees of freedom of twisting motion to the thumb (Hoshino and Kawabuchi, 2005).

Robot locomotion: As a human, walking by legs is easy. However, it is not an easy task when introducing it to a humanoid robot. The humanoid robots available today are using bipedal locomotion technology. Currently, there are two approaches used in the bipedal walking field and one of them is the Zero-Moment-Point theory (ZMP). ZMP is defined as the point on the ground where the net moment of the inertial and gravity forces has no component along the axes parallel to the ground (Erbatur *et al*., 2002). The trajectory of ZMP plays an important role in balancing the robots during walking. For a feasible walking pattern, ZMP trajectory must lie within the supporting polygon defined by the location and shapes of the supporting feet.

There are a lot of humanoid robots are designed based on ZMP-based control, for example the Asimo by Honda and WABIAN bipedal humanoid robot developed in Japan (Yamaguchi *et al*., 1999). Another humanoid robot named QRIO was also developed in Japan. Apart from walking, it can perform activities such as running and jumping. The researchers used the ZMP stability criterion in order to achieve stable run and jump (Nagasaka *et al*., 2004). It demonstrated the humanoid robot's motion is more human-like with this technology. Another approach is the passive dynamic walking method which introduced by McGeer. This method allows the humanoid robot walks down a slope without motors or controllers (Trifonov and Hashimoto, 2008). The energetic efficiency of the robot using this method is higher (Ni *et al*., 2009). It is easy to control with the foot contact sensors. However, there are some limitations for this technology such as the inability to stand still due to the round feet used, the inability to start or stop walking and inability to change the speed and direction. Therefore, some improvements have been carried out such as installing the actuators to the walking robots and installing direct drive or elastic actuators at some of the joints of the biped of the robot (Omer *et al*., 2009).

Robot learning behavior: A humanoid robot is able to communicate to human with facial expression and hand gestures. It even has the ability to use its hand to carry things and move from place to place. However, all of these are still not sufficient in our daily activities, the humanoid robot should be able to adapt existing capability, cope with changes and able to learn new skills quickly.

In order to achieve the requirement, some techniques can be applied to the humanoid robot such as imitation learning (Schaal, 1999). Imitation learning means repeat that motion immediately and keep into the memory when a third party demonstrates a motion. For humanoid robots, the external motion captures system which is depending on special sensors. There are known as markers which used to sense the motion. Sometimes, it is difficult for a humanoid robot to imitate human actions. For example, some human motions cannot be mimicked by the robot due to the limitations of joints angle or dynamic constraints as well as lack of joints. There is another similar technique which is called programming by demonstration. This technique allows the robot to observe the task performed by a human. Then it extracts the information from the demonstration and maps the information into an abstract. Eventually, generating the appropriate robot motion (Zollner *et al*., 2004; Calinon and Billard, 2007).

Another technology which optimizes the learning behavior of humanoid robot is the reinforcement learning. This method enables a humanoid robot to improve its behavior on sequential decision-making tasks. By this technique, the behavior of the robot will be improved since the troublesome step-by-step programming has been eliminated. There are a number of methods have been implanted into this technique such as reinforcement learning with Decision Trees (Hester *et al*., 2010). This method will be generalized aggressively during model learning, so the number of trials required for learning will be limited. Many studies have applied reinforcement learning task in a discrete low-dimensional state space. However, a continuous high-dimensional state space should be applied in order to control the humanoid robot smoothly. Therefore, researcher has proposed method for adaptive allocation, which is Allocation/Elimination Gaussian Soft max Basis Function Network (AE-GSBFN) in order to avoid the problem (Lida *et al*., 2004).

APPLICATIONS

The development of humanoid robot advances from time to time. In the past, the humanoid robot is only used in home applications and for entertainment. However, the continuous improvement process of technology, nowadays, the humanoid robot can be applied in many fields such as healthcare, sport, space exploration, construction and industry and even education. The applications of humanoid robot in different fields are discussed in the following sections.

Home applications: This is the era that people are busy with work and always leave their home unoccupied. So there is a need to have a robot to look after their house in their absence. Therefore, a system had been developed by researchers in Japan that enables users to control one or more humanoid robots in their houses remotely with a mobile phone or the internet (Sawasaki *et al*., 2003). This helps the users to perceive the conditions at the robot's site. The users can pre-define some locations in the house and assign some operations to the robot, so that the humanoid robot can walk to the pre-defined locations and execute the tasks based on user's requirement while the house is unoccupied.

Entertainment: The humanoid robots are becoming increasingly popular for providing entertainment too. The humanoid robots are very good in communication with the human with the facial expression, hand gestures and other body languages. There are many humanoid robots being developed for the application of entertainment. One of the examples is the small humanoid type robot, SDR-4X. It has the ability to walk on the unbalanced surface and it is able to avoid obstacles while walking in real world home environment. The performance of SDR-4X includes the dynamic and smooth dancing and it is composed by a program called SDR Motion Creator. The main performances that SDR-4X can perform are dancing and A Cappella Chorus performance. In addition, SDR-4X can also learn and identify the user faces and names as well as interact with the user via its synthetic voice (Fujita *et al*., 2003).

Healthcare: Humanoid robots have the human-like features such as walk in a biped way and communicate with people just like human. In hospital, humanoid robot can be used as a service robot to assist nurses and patients in their activities and also help the people in remote site to communicate with people in hospital (Nishiyama *et al*., 2003). In hospital, humanoid robot has become the nurse's avatar as the robot is able to talk and understand the needs of the patient. For patient, humanoid robot helps the patients who are inconvenience to move. Patient can also communicate to robot and regard the robot as another existence of users.

Autism is one of the pervasive developmental disorders. There are many children with autism may have difficulties in their daily activities e.g., communication, social interaction and imagination. In this matter, robots can be used as the therapeutic tool. There are two different types of humanoid robots which are especially developed to help the children with autism. The two humanoid robots are IROMEC and KASPAR. IROMEC is a mobile robotic platform and it has an interface with a cartoon-like character. KASPAR is a small scale humanoid robot. Both humanoid robots engage children with autism in social interaction and communication skills (Iacono *et al*., 2001).

Sport: Sport is another important activity for human. Because of this, researchers also study the possibility for a humanoid robot to involve in sport. Fast and flexible walking is an important criterion for a humanoid robot in Robocup soccer competition. The main challenge of doing that is the instability. In order to solve this problem, the researcher proposed a new fuzzy-logic control scheme that enables the robot to achieve fast and flexible walking as well as high stability turning. This can be done by incline walking and setting the step length carefully. A fuzzy algorithm is applied to find the proper angle of the joint so that the robot will have proper reaction under various body situations. A humanoid robot, EFuRIO was developed for this purpose. Current version (third generation) has the ability to stand, walk, turn and kick (Sulistijono *et al*., 2010).

Space: Another field that the humanoid robot started to penetrate is the application in space. The researchers started to study the suitability of humanoid robot in replacing human to enter the space. It is due to the human life support in space is very costly and space missions are always dangerous. The researchers have a vision to make humanoid robots in replacing human in future space exploration. Humanoid robot offers a number of advantages which include:

- Easy communicate with
- Its hand performing impressive acts of dexterity and skillful as well as
- The current efficiency of teaching and programming a robot is very high with humanoids (Stoica and Keymeulen, 2006)

The National Aeronautics and Space Administration (NASA) had worked together with General Motors to develop the space humanoid. Finally, a new generation of humanoid robot named Robonaut 2 was born (Diftler *et al*., 2011). Robonaut 2 was the first humanoid robot that was sent to the International Space Station in 2011. The main function of Robonaut 2 is working side-by-side with human astronauts. It can actuate switch, manipulate tool and grasp of hard and soft objects. Robonaut 2 is served as a flexible assistant of the astronauts.

Construction and industry: It is important in replacing humans with humanoid robots for dangerous job in the site. For example, construction machinery and equipment play an important role in many tasks at the site. Very often, human exposure to hazardous while operating the machinery and equipment. If a humanoid robot can operate the machinery and equipment and the robot can be communicated from a remote site, then it will solve the problem of dangerous jobs. Humanoid robot also plays important role is in a disaster site where a construction machine is required to move away some big and heavy objects. It is dangerous for a human operator to work in a disaster site. In Japan, the researchers have developed a humanoid robot called HRP-1 (Hasunuma *et al*., 2002). It utilizes the proxy drives of the construction machines such as a lift truck via tele-operation. This humanoid robot can be operated according to the command sent by the remote computer.

The humanoid robot has a limitation of handling and lifting heavy objects. Most of the humanoid robots are limited to the posture of the end-effectors only landing. If the humanoid robot can contact the surrounding objects arbitrary, it will be able to handle and lift heavier objects. Therefore, the researcher had proposed a “whole body contact motion” technology. Its controller has the distributed tactile sensors to control the contact state. With this technology, the humanoid robot can lift a 30 kg box by tactile feedback (Ohmura and Kuniyoshi, 2007).

Education: Besides the applications above, some researchers also started to move to the education. A humanoid robot called Bioloid was developed by the robot manufacturer called Robotis in Korea. Bioloid is a hobbyist and educational robot kit which is aimed to serve as a teaching assistant which provides an interactive learning environment to students (Chin *et al*., 2011). The researcher also proposed an IDML tools for teachers to generate teaching materials and planning of the humanoid robot’s motion. Besides, IDML tools provide a platform for students to interact with the humanoid robot that involve some learning activities. The educational robot, Bioloid gives a good impression to students and able to grab the students’ attention in the class.

CONCLUSION

Humanoid robot is a very interesting field of study with its ability of getting information from its surrounding and carrying out physical work just like human. The general concept of humanoid robot is using different type sensors to acquire information and performing different task based on the acquired information by using the facial expressive head, hands, body and legs. The study of humanoid robot has been started in the past four decades, from years to years, new technologies will be introduced to replace or advance from the old technologies. Many researches get inspired from the science fiction film such as “Star Wars”, “Real Steel” and “Transformers” movies and series. The recent developed humanoid robots are getting closer and closer to human behavior. Some of the popular humanoid robots are the ASIMO by Honda, which is an astronaut look-alike robot, HRP-4 by Kawada, a slim, fast and advanced robot developed by the Japanese government and Nao by Aldebaran, one of the cutest and most intelligent robots. All of these humanoid robots are acting like a human.

This study has studied the current techniques and technologies used by the researchers such as the human-robot communication technique, hand and locomotion system as well as the learning behavior technology has been explained and discussed. In the past, humanoid robot was developed for display purpose instead of special function or real application. With the advancement of the technology in recent years, humanoid robots have been started to be applied in different fields as discussed in this study. However, all the developed robots are still in the research phase and not really be applied in the real world. The future trend and the challenges of the humanoid robot are discussed. If the challenges mentioned can be solved, humanoid robots will give us a better quality and more comfortable life.

RECOMMENDATIONS

After many years of research on humanoid robots, the researchers have obtained an impressive result. From a robot which only did task-by-task setting by human to a robot which can communicate with human, from a robot with just gripper and roller to move and do job to a robot with hands and legs just like human, the researchers' contribution to the great success of the world. However, no matter how much money is spent on research and development and how advanced technology is changing, when humanoid robot will be common in the society? This question is actually a very big challenge facing by the world. However, this will not discourage further research of the humanoid robot and it is believed that humanoid robot will become common in future world. However, how long need to be taken is unknown.

In future, the humanoid robots are expected to have better perception ability. More advanced methods will be developed to deal with the ambiguities of the sensory signals. The continuous improvements in computer vision and speech recognition systems will enhance the ability of a humanoid robot to communicate with human (Behnke, 2008). For the mechanical parts, muscle-like actuators will be introduced for safety operation of humanoid robots in the close vicinity to human. The movement of the hand, especially the finger of the humanoid robots, will become smoother just like human hand. In addition, the humanoid robots will offer more variety in its applications. For example, invention of an undersea humanoid robot can replace human who face the limitation of mobility and breathing problem when going deeper into the sea (Mohanty *et al*., 2010). All of the issues mentioned above will be the future challenges for the researchers.

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