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Analysis of Biped Humanoid Robot

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Abstract— **This paper describes the design analysis of a biped humanoid robot and their uses in day today life. A human like autonomous robot which is capable to adapt itself with the changing of its environment and continue to reach its goal is considered as Humanoid Robot. These characteristics differs the Android from the other kind of robots. In recent years there has been much progress in the development of Humanoid and still there are a lot of scopes in this field. A number of research groups are interested in this area and trying to design and develop a various platforms of Humanoid based on mechanical and biological concept. Many researchers focus on the designing of lower torso to make the Robot navigating as like as a normal human being do. Designing the lower torso which includes west, hip, knee, ankle and toe, is the more complex and more challenging task. Upper torso design is another complex but interesting task that includes the design of arms and neck. Analysis of walking gait, optimal control of multiple motors or other actuators, controlling the Degree of Freedom (DOF), adaptability control and intelligence are also the challenging tasks to make a Humanoid to behave like a human. Basically research on this field combines a variety of disciplines which make it more thought-provoking area in Mechatronics Engineering.**

I. INTRODUCTION

A bipedal robot can be generally described as the types of autonomous system this can imitate human waling motion with maintaining postural stability during the motion. A humanoid robot is a robot that not only resembles human's physical attributes especially one head, a torso, and two arms but also should have the capability to communicate with humans and other robots, interpret information, and perform limited activities according to the user's input. Humanoid robots are equipped with sensors and actuators. These robots are typically pre-programmed for determined specific activities. Based on typical applications, humanoid robots can be categorized into Healthcare, Educational and Social humanoid robot. Healthcare humanoid robots are used by patients at home or healthcare centers to treat and improve their medical conditions. These robots either require a human controller or are fully preprogrammed to assist patients. Educational humanoid robots are for students and are used in education centers or home to improve education quality and increase involvement in studies. These robots are typically manually controlled robots. Social humanoid robots are used by individuals or organizations to help and assist people in their daily life activities. These robots are commonly preprogrammed to perform mundane tasks and are also known as assistive robots.

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II. HISTORY

The concept of human-like automatons is nothing new. Already in the second century B.C., Hero of Alexander constructed statues that could be animated by water, air and steam pressure. In 1495 Leonardo da Vinci designed and possibly built a mechanical device that looked like an armored knight. It was designed to sit up, wave its arms, and move its head via a exible neck while opening and closing its jaw. By the eighteenth century, elaborate mechanical dolls were able to write short phrases, play musical instruments, and perform other simple, life-like acts.

In 1921 the word robot was coined by Karel Capek in its theatre play: R.U.R. (Rossum's Universal Robots). The me-chanical servant in the play had a humanoid appearance. The rst humanoid robot to appear in the movies was Maria in the lm Metropolis (Fritz Lang, 1926). Westinghouse Electric Cor-poration exhibited at the 1939 and 1940 World's Fairs the tall motor man Elektro. Humanoid in appearance, it could drive on wheels in the feet, play recorded speech, smoke cigarettes, blow up balloons, and move its head and arms. Elektro was controlled by 48 electrical relays and could respond to voice commands.

Humanoid robots were not only part of the western culture. In 1952, Ozamu Tezuka created Astroboy, the rst and one of the world's most popular Japanese sci- robots. In 1973 the construction of a human-like robot was started at the Waseda University in Tokyo. Wabot-1 was the rst full-scale anthropo-morphic robot able to walk on two legs. It could also communi-cate with a person in Japanese and was able to grip and trans-port objects with touch-sensitive hands. The group of Ichiro Kato also developed Wabot-2, which could read music and play an electronic organ. It was demonstrated at the Expo 1985 in Tsukuba, Japan. Wabot-2 was equipped with a hierarchical sys-tem of 80 microprocessors. Its wire-driven arms and legs had 50 degrees of freedom.

Many researchers have also been inspired by the movie Star Wars (George Lucas, 1977) which featured the humanoid robot C3-PO and by the TV series Star Trek - The Next Generation (Gene Roddenberry, 1987) which featured the humanoid Data.

In 1986 Honda began a robot research program with the goal that a robot "should coexist and cooperate with human beings, by doing what a person cannot do and by cultivating a new dimension in mobility to ultimately bene t society." After ten years of research, Honda introduced in 1996 P2 to the public, the rst self-contained full-body humanoid. It was able to walk not only on at oors, but could also climb stairs. It was followed in 1997 by P3 and in 2002 by Asimo.

In the U.S. Manny, a full-scale android body, was completed by the Paci c Northwest National Laboratory in 1989. Manny had 42 degrees of freedom, but no intelligence or autonomous mobility. Rodney Brooks and his team at MIT started in 1993 to construct the humanoid upper-body Cog. It was designed and built to emulate human thought processes and experience the world as a human.

Another milestone was the Sony Dream Robot, unveiled by Sony in the year 2000. The small humanoid robot, which was later called Qrio, was able to recognize faces, could express emo-tion through speech and body language, and could walk on at as well as on irregular surfaces.More recent examples of humanoid robot appearances in the movies include David from A.I. (Steven Spielberg, 2001), and NS-5 from I, robot (Alex Proyas, 2004).

III. HUMANOID ROBOTICS

A humanoid robot is a robot with its overall appearance based on that of the human body. In general humanoid robots have a torso with a head, two arms and two legs, although some forms of humanoid robots may model only part of the body, for example, from the waist up. Some humanoid robots may also have a 'face', with 'eyes' and 'mouth'. Androids are humanoid robots built to resemble a male human, and Gynoids are humanoid robots built to resemble a human female.

BIPED LOCOMOTION

The distinctive feature of full-body humanoids is bipedal loco-motion. Walking and running on two legs may seem simple, but humanoid robots still have serious di culties with it. I see two opposing approaches to bipedal walking. The rst-one is based on the zero-moment-point theory (ZMP), introduced by Vuko-bratovic [1]. The ZMP is de ned as the point on the ground about which the sum of the moments of all the active forces equals zero. If the ZMP is within the convex hull (support poly-gon) of all contact points between the feet and the ground, a bipedal robot is dynamically stable. The use of the ZMP to judge stability was a major advance over the center-of-mass projection criterion, which describes static stability. Prominent robots, which rely on ZMP-based control, include Honda Asimo and Sony Qrio. Asimo was shown in 2006 to be capable of 6km/h running. However, its gait with bent knees does not look human-like. It does not recycle energy stored in elastic elements, the way humans do it and, hence, it is not energy-e cient. Furthermore, Asimo requires at, stable ground for walking and running and can only climb certain stairs.

A completely di erent approach to walking is to utilize the robot dynamics. In 1990 McGeer showed that planar walking down a slope is possible without actuators and control [2]. Based on his ideas of passive dynamic walking, actuated machines have been built recently [3]. These machines are able to walk on level ground. Because their actuators only support the inherent machine dynamics, they are very energy-e cient. They are easy to control, e.g. by relying on foot-contact sensors. However, because they use round feet, these machines cannot stand still. So far, these machines can also not start or stop walking and are not able to change speed or direction.

What is missing in current humanoid robots is the ability to walk on di cult terrain and the rejection of major distur-bances, like pushes. Such capabilities were demonstrated by the quadruped BigDog [4]. This robot, however, is not suited for indoor use due to its combustion engine and hydraulic actuators. First steps towards bipedal push recovery have been done in sim-ulation using Pratt's concept of capture point [5]. It is di cult to transfer these simulation results to physical robots, partly due to the lack of suitable actuators. Although hydraulic actuators (e.g. Sarkos biped used at ATR and CMU) and pneumatic ac-tuators (e.g. Lucy designed at Brussels [6]) have been used for bipeds to implement compliant joints, their walking performance is still not convincing.

Perception

Humanoid robots must perceive their own state and the state of their environment in order to act successfully. For proprioception, the robots measure the state of their joints using encoders, force sensors, or potentiometers. Important for balance is the es-timation of the robot attitude. This is done using accelerometers and gyroscopes. Many humanoid robots also measure ground re-action forces or forces at the hands and ngers. Some humanoid robots are covered with force-sensitive skin. One example for such a robot is CB^2 [7], developed at Osaka University.

Although some humanoid robots use super-human senses, such as laser range nders or ultrasonic distance sensors, the most important modalities for humanoid robots are vision and audition. Many robots are equipped with two movable cam-eras. These cameras are used as active vision system, allowing the robots to focus their attention towards relevant objects in their environment. Movable cameras make depth estimation from disparity more di cult, however. For this reason, xed calibrated cameras are used for stereo. Most humanoid robots are equipped with onboard computers for image interpretation. Interpreting real-world image sequences is not a solved problem, though. Hence, many humanoid vision systems work well only in a simpli ed environment. Frequently, key objects are color-coded to make their perception easier.

Similar di culties arise when interpreting the audio signals captured by onboard microphones. One major problem is the separation of the sound source of interest (e.g. a human com-munication partner) from other sound sources and noise. Turn-ing the microphones towards the source of interest and beam-forming in microphone arrays are means of active hearing. While they improve the signal-to-noise ratio, the interpretation of the audio signal is still di cult. Even the most advanced speech recognition systems have substantial word error rates.

Due to the described di culties in perception, some hu-manoid projects resort to teleoperation, where the signals cap-tured by the robot are interpreted by a human. Examples for teleoperated humanoids include the Geminoid [8] developed by Ishiguro, the Robonaut [9] developed by NASA, and the PR1 [10] developed at Stanford.

Human-Robot Interaction

Many humanoid research projects focus on human-robot inter-action. The general idea here is that the e cient techniques which evolved in our culture for human-human communication allow also for intuitive human-machine communication. This includes multiple modalities like speech, eye gaze, facial expres-sions, gestures with arms and hands, body language, etc. These modalities are easy to interpret by the human sensory system. Because we practice them since early childhood, face recogni-tion, gesture interpretation, etc. seem to be hard wired in our brains. A smile from a robot does not need much explanation.

In order to address these modalities, communication robots are equipped with expressive animated heads. Examples include Kismet and Leonardo, developed at MIT [11, 12], and WE-4RII developed at Waseda [13]. Movable eyes, head, and chests com-municate where the robot focuses its attention. When the robot looks at the interaction partner, the partner feels addressed. Some robots animate their mouth while generating speech. This helps the listener to detect voice activity. Some robots have an emotional display. By moving eyebrows, eyelids, the mouth, and possibly other parts of the face, a number of basic emotions can be expressed. The expression of the emotional state can be sup-ported by adapting pitch, loudness, and speed of the synthesized speech.

Robots with anthropomorphic arms and hands can be used to generate gestures. At least four joints per arm are needed [14]. One example for a upper-body robot used to generate a variety of gestures is Joy, developed at KAIST, Korea [15]. The gener-ated gestures of humanoids include symbolic gestures, such as greeting and waving, batonic gestures, which emphasize accom-panying speech, and pointing gestures, which indicate a direction or reference an object. The size of objects can also be indicated with arms and hands. The robot head can be used for pointing, nodding and shaking as well. Robots with articulated ngers like Hubo, also developed at KAIST [16], may even be used to generate sign language.

Full-body humanoids can use their entire body for commu-nication using body language. Wabian-RII, for example, was programmed to generate emotional walking styles [17]. Another example is HRP-2, which reproduced a Japanese dance captured from a human dancer [18].

The most extreme form of communication robots are an-droids and gynoids, which aim for a photorealistic human-like appearance. Their faces are covered with silicone skin, they have human-like hair, and they are dressed as humans. Some of these robots are modeled after living persons, such as Repliee Q2, de-veloped in Osaka [19], and the copy of Zou Ren Ti, developed at XSM, China. These robots, however, heavily su er from the uncanny valley e ect [20]. There is not a monotonous increase in attractiveness as robots become more human-like, but there is a sudden drop in attractiveness close to perfect human-likeness.

While the synthesis-part of multimodal interaction works reasonably well, the insu cient perception performance of the computer vision and audition systems and the lack of true mean-ing in the dialogue systems so far prevent humanoid robots from engaging in truly intuitive multimodal interactions with humans.

IV. APPLICATIONS

Humanoid robots have been used in the field of healthcare and education. The majority of the study involved minors and senior citizens; However, economic feasibility was not tested in any study included in this paper.

The following section briefly discusses the influence of age, gender, and other experimental setups on human behavior toward humanoid robots and their application specifically in the field of healthcare and education.

Healthcare Humanoid Robot: Healthcare practitioner and benefactors have appreciated the advantage of advanced surgical robots. However, our study highlights the application of humanoid robots and their roles in healthcare. In addition to surgical robots, healthcare humanoid robots have been successfully helping people in disease management, pain relief, pediatric healthcare assistant, and physical therapy. The role of healthcare robots can be broadly classified into the clinical and non-clinical application.

Clinical application:

In Clinical setting, humanoid robots have been used to assist patients with cerebral palsy [21], and pediatric cancer [22]. To study the influence of human-robot interaction two children of age 9 and 13 with cerebral palsy were exposed to NAO robot under four different interactive situations. The experiment aimed at improving patient coordination, truncal balance and motor function [21]. The first interaction was a general introduction round where children and robot verbally communicated with each other. In this situation, the subject had a tough time understanding the robot and required the help of a therapist; thus, it increased positive interaction between the subjects, humanoid-robot, and the therapist. This was aimed to enhance a child's social adaptability [21]. The second, third, and fourth interaction session was an imitation round which aimed at improving the lower leg balance and function. In this setup, the children had to imitate the movements of the humanoid robot by lifting one leg and kicking a ball [21]. No improvement was observed during this setup; however, the children developed a positive interaction with the humanoid robot [21].

The essential responsibilities of the robot in the clinical healthcare domain are mollification of distress [23], remote monitoring [24], and interacting with the patient [21]–[25]. To measure the impact of a humanoid robot in pain and distress mollification, "Face Pain Scale-Revised" [23] approach was taken during the vaccination of children in a clinical setup. The pain experienced by the children during an injection shot was measured through their facial expression and behavior such as crying and muscle tension. Children felt more pain during vaccination in the absence of a robot in the clinic [23] than in their presence. Moreover, studies on the effect of a humanoid robot on anger, anxiety, and depression level have also been significant. To study the effect of humanoid robots on anger, and anxiety, "social robot-assisted therapy" [22] and psychotherapy were compared by giving individual psychotherapy and psychotherapy using a humanoid robot to a different group of children with cancer. The group assisted by the humanoid robot had eight sessions in which the robot played different roles such as a doctor, chemotherapist, nurse, cook, ill kid and other. In these sessions, the humanoid robot interacted with the children and explained to them the role of each character in a story form to reduce their anger, depression, and anxiety. Post the experiment a questionnaire was used to assess anger, fear, and depression level of the children. It was observed that the robot-assisted group had lower anxiety, depression, and violence than that of the controlled group. Thus, humanoid robots were successful in minimizing anger, anxiety, and depression [22] among cancer patients. Humanoid robots also enhanced joint attention between the patient and the therapist [26].

Non-clinical application:

Non-Clinical healthcare have significantly contributed to autism management followed by diabetes management [27] by performing activities such as playing games [28]–[30], greeting, singing, dancing, hand movement, blinking, interacting with the patients [22], [23], [21]–[33]. Robots also measured blood pressure [34]–[36] and asked questions, played a quiz with the patients [27][37], monitored and helped patients with medical assistance [24].

The effect of using robots in autism management has been highly effective and appreciated. Humanoid robots can be used to foster social and behavioral skills within autistic children [28], thus, can improve patient's autistic behavior [39]–[41].

Gaze is a crucial medium that enables social communication. It also affects acceptance, preference, and obedience among human beings [19]; However, excessive gaze might impose a threat, superiority, and anger [29]. Fifty-two University students participated in an experiment in which they had to engage in the "shell game" [29] with a humanoid robot. The game consisted of three different levels of difficulty. A mixed 3 X 3 design was employed to study the behavior of the subjects at Averted gaze, constant gaze and situational gaze [29] for the easy, medium and hard difficulty level of the game. Here, the independent variable was the three levels of gaze and game difficulty level — averted gaze in which the robot never looked at the participant, constant gaze during which the robot continuously seemed at the participant and situational gaze when the robot looked at the participant only when he or she gave a wrong answer. It was observed that with an increase in difficulty participant's trust towards the humanoid robot increased.

Use of humanoid robot had a significant influence on communication, social behavior and joint attention of autistic patients [22], [23] but did not influence any collaborative behavior among patients [10]; However, playing with human adult enhanced collaboration among patients [24].

Education Humanoid Robot:

Use of computer and e-learning in the field of education have been performing well and have successfully increased the accessibility to education worldwide. However, the recent trend in education domain is towards the application of humanoid robots. Humanoid robots are now on the verge of becoming an essential component in the field of education as these robots can reason and analyze situations logically to support human learning and are also better than computer agent [28] and more engaging than the virtual agent [29]. Comparison between a projected robot, a collocated robot, and an on-screen agent has been a relevant concern in the domain of education and e-learning. To compare the impact of a computer agent, on-screen projection, onscreen projection of a robot and a physical robot on the social behavior such as engagement, disclosure, influence, memory, attitude, and others were measured to find that collocated or physical presence of robot-enhanced participant's involvement [28] with the subject. However, it did not affect social behavior [28]; Moreover, there was no significant difference found between onscreen robot, and a collocated robot [28]. Unlike other studies, this showed that learning ability was minimum using an arranged robot [28]. Humanoid robots have been known for teaching language [30] [27], hands-on engineering [31], nutrition [32], mathematics [33], general science [34] as well as helps students in learning spellings, storytelling [35] and participate in memory games. Robots have been performing the role of a teaching assistant [36], and games partner of children.

In most of the studies, humanoid robots were used along with a human teacher or a controller. The educational humanoid robots have been used for various sections of education and have addressed wide range of students such as preschool kids [35] , primary school kids [27], [33], [35], [28], [30], [24] junior high school students [36] and undergraduate engineering students. Students responded positively to the robots. Positive effect on learning [33] was observed along with higher participation [34]. Increase in a student's creativity, curiosity, knowledge, and recall rate [29], were observed.

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