Importance of Locomotion and Its Dominance over Other Factors

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***Abstract*—Humanoid robots are defined as a robot which is created with the idea that it resembles a human being in not just its appearance but also displaying emotions, forging relationships, making decisions, and developing as they learn through interactions with the environment. However, even though these aspects of humanoid robots are important what brings it closest to a human as compared to other robots is its ability to walk like them. Various aspects of the locomotion mechanism have been brought to light in this paper. The work of some researchers has been reviewed to draw up a better understanding of the current research that has been going on and how it has changed the visage of locomotion of humanoids today. Factors such as Zero Moment Point, importance of the usage of Central Pattern Generators, the Gaits algorithm, exploratory gaze movements, the various locomotion control techniques and the room awareness algorithm with self-localisation strategies, have been discussed to demonstrate how they have influenced the efficiency and effectiveness of a humanoid.**

***Index Terms*—Humanoid robot, bipedal locomotion, ZMP, CPG.**

I. Introduction

A **machine** is made up of one or more parts and is one that uses energy to complete specific tasks [1]. One such machine was created in the year 1954 by George Devol [2]. Little did he know that this magnificent creation was about to revolutionize the entire face of mankind. The first ever electro-mechanical device of its kind, called a robot was primarily made up of legions of circuits and usually operated using a highly convoluted computer program [3]. Initially Unimate, the first robot was created with the purpose of lifting pieces of metal from die casting machines. With the advent of robotics, the life of human beings became easy, as robots can now perform any task, starting with daily household chores all the way to manufacturing products at a large scale in industries [2]. One such robot was the humanoid robot which was invented in 1973 at the Waseda University, in Tokyo. Wabot-1 was the first humanoid robot. It was able to walk as well as measure distances and directions to the objects using external receptors. It could also communicate with a person in Japanese [4]. Defining a humanoid robot is a very complex task as it is equivalent to describing what it means to be human. The motive is not to recreate humans but to make something similar that can be used interchangeably with human beings [5]. The body structure of a humanoid is anthropomorphic. Most of the humanoids even display emotions and intelligence similar to that of their human counterparts. A humanoid design was designed with two purposes, firstly, a functional purpose such as interacting with human tools and environments and secondly, for experimental purposes, such as the study of bipedal locomotion [6]. While various industrial robots have left a mark in the industrial mass production, we now need robots with a slightly different perspective: for general purpose applications. Humanoids along with doing several household tasks can also be used to test models of aspects of human intelligence. Some of the humanoid robots can do things which people can do and also which people cannot do. They can teach or read to children with autism and even help differently abled children. They never make mistakes thereby inculcating a sense of guarantee [7]. These are some of the advantages of humanoids over other robots. There are various factors that differentiate a humanoid robot from other robots.

1) They walk and look human-like. They have a torso, a head, two arms and two legs.
2) Facial expressions can determine various moods, very much like their human counterparts.
3) They develop as they learn through interactions with human beings and various other entities.
4) They can adapt to unanticipated circumstances when restricted to unfamiliar environments.
5) They can forge relationships.
6) They can perform tasks with commands given through gesture and speech.
7) They can adapt their own unique experiences with the world. [8]

The locomotion mechanism of a humanoid is its most critical factor. The various locomotion techniques include wheeled, bi-pedal, walking, running, rolling, hopping, swimming, meta-chronal motion and brachiating. Wheeled robots are usually the most energy efficient because an ideal rolling wheel loses no energy. Bipedal walking uses passive dynamics and Zero Moment Point. When not drawing energy from a supply, the dynamic behavior of actuators in robots is called passive dynamics [9]. Zero Moment Point is related with dynamics and control of legged locomotion [10]. For the sake of simplicity most mobile robots have four wheels or a number of continuous tracks. More complex wheeled robots have been created with only one or two wheels. These can have certain advantages such as greater efficiency and lesser parts. Initially, a robot with only one leg could stay upright by hopping. The movement is the same as that of a person on a pogo stick. As the robot falls to one side, it would jump slightly in that direction, in order to catch itself. This algorithm was then generalized to two and four legs. Coordinated sequential action resembling

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a traveling wave is called meta-chronal rhythm and this is used by robots for locomotion [11].

The current research in the field of robotics primarily focuses on the behavioral aspects of a humanoid robot. Learning of behaviors is given a lot of importance where a robot learns from successful execution of certain tasks [12]. This is important as the robot becomes self-dependent as well as self-learned but the bipedal locomotion aspect of a humanoid is what sets it apart from other robots in the community. Also, autonomous, efficient and effective locomotion is the most underdeveloped making it an important issue to discuss in the research community. Thus, there is a need to review the various characteristics of locomotion and the state-of-the-art work done by researchers till date on locomotion of humanoids.

II. Discussions

In the paper by **Rokbani** *et al.*, the key point highlighted is bipedal locomotion. They proposed a hybrid algorithm for walking gaits generation as an alternative to using kinematics and dynamic equation solving. This idea can be applied to small humanoids with 6 degrees of freedom. Of the several issues fixed while building humanoids, some of them are building robots with human like capabilities in motion control, gestures and postures. The importance of limiting the number of legs to 2 is brought to light. Gaits analyses are introduced to analyze and enhance motion dynamics. Biped robots evolution has been discussed with several examples such as the WL1 from Japan, ASSIMO by HONDA, QRIO by Sony, HRP2, NAO from France and various other research projects developed in France, Belgium, Italy and Deutschland. There is a limited degree of freedom faced by humanoids compared to humans. Human motions result from flexion and extensions, the effectiveness of which was assumed and pneumatic muscles proposed which has been used in the Lucy Biped. In the humanoid locomotion system the rotations depend on the skeleton structure and the actuators specifications, but most bipeds adhere to the human joints angular elongation limits. An experiment was conducted with the use of classic marking methodology, under the supervision of biomechanics' walking specialists to collect human gaits. Human anthropometry was used to get an approximation for the humanoid body segments dimensions. Swarms architecture is composed by two sub-swarms: left foot and right foot. The gaits from this experiment were useful in understanding the walking mechanism and these gaits are used as a framework for different simulated approaches. Since only six walkers were used in the biomechanics experimentation process, the joints extracted are limited. The proposal is based on particle swarm optimization, which belongs to evolutionary computing based on a simple equation fast enough to compute, with low memory cost. The convergence of this algorithm is that a slight dissymmetry is observed in the robot and also, it does not ensure a complete walking cycle generation [13].

Looking at the **motion control** in a humanoid robot, following are the motion based controls - inverted pendulum dynamics, zero moment point control and biologically inspired control methods using neural networks. The main aim of the study done by **Baydin** was the application of Gaits Algorithm (GA) optimization, further for the creation of Central Pattern Generators (CPG) networks in a realistic simulated environment under fitness evaluations. The CPG usage in robots increased with time but they were only specific to particular applications. There arose a need to develop generic methods and design principles for creating individual networks. The CPG control is applied to five-link planar bipedal walking mechanism, which is a minimalistic structure made of 4 actuators corresponding to the knee and hip of each leg and touching the ground without ankles. The five-links are two links for each hip, two links for the knee joint and the fifth link connecting the two joints. The omission of feet is done to increase the stability of the 2D model. For optimization of the parameters relating to CPG networks, standard GA is implemented. The parameters include internal connectivity structure and presence and strength of feedback pathways from the walking mechanisms. Fitness evaluations of the five-link mechanism are done with a set of parameters subject to evolution, forming the hardware implementation. The connections between the hip and knee are unidirectional due to which there can be an effect on knee unit oscillators from corresponding hip on its side, but not the other way. 25 real numbers constitute the parameters of the CPG network. Hardware implantation is done in 2D by using an attached lateral boom rotating around a pivot. The lateral boom restricts the movement of the mechanism to a spherical surface. The hand-tuning approach was very hard to achieve, the gait seemed unnatural and eventually destabilized after 3 or 4 steps. After 10 generations of fitness evaluations, the best fitness reaches a point that is determined by the maximum speed of actuators and the mass and dimensions of the mechanism. CPG shows great versatility, and stable gaits were found even after the first generation. It was also found that the knee unit uses feedback more than the hip units. The impact of asymmetry in unequal distances covered by left and right feet was larger than anticipated. Future-CPG can be used for far more complicated mechanisms. Feedback can be left out under the presence of obstacles and in dynamically changing environments, to walk in 3D without support structure. The limitations included feedback issues. Also, the experiment was conducted neither in the presence of obstacles nor in dynamically changing environments [14].

A programmable CPG is used for generating curvilinear bipedal walking patterns which are then able to generate rhythmic and periodic trajectories for a Nao soccer player robot as mentioned in the paper by **Shahbazi** *et al.* The inspiration for the CPG came from locomotion structures in vertebrate animals. A curvilinear pattern for walking Nao robots on a specified circular curve was made from new equations that were extended from the programmable CPG. To control the arms and their synchronization with the feet some specific equations were also added. Sensory inputs were installed in the model to obtain some feedback from the movement and adjustments were made conforming to potential perturbations. The feedback values adopted walking to some desired specifications and the effects of some types of perturbations were compensated. The bottom of the foot had foot pressure sensor values and accelerator values that summed up the input sensory values. The various benefits of the proposed model included modulation during walking and smooth walking patterns. This model can be extended and used in the Nao soccer player for the 3D soccer simulation leagues of RoboCup SPL competitions to train different types of motions as well as for the standard platform. Neuroscience and robotics together converge at the base of the problem of robot locomotion. There are some methods that use pre-recorded trajectories. These methods are offline and do not use feedback from robot sensor, the only aim is to find the best ones to use in locomotion and optimize the trajectories. The ZMP method uses the dynamic model of a robot and calculates the point in which all the momentums of the robot converge to zero and this point is kept in a safe area. The CPG based method encodes rhythmic trajectories. The first stage experiments were performed in MatLab using the Simulink toolbox. The training of the CPGs was a part of the first stage experiments. The online controlling of the robot which was the second stage was an integrated simulation of the Nao robot in Vebots robots stadium. In the 2nd phase trained state values were imported to the VebotNao model and the designing of controller of curvilinear walking takes place in the robot stadium environment. The main source of feedback is the foot sensor values which are used in the model which controls curvilinear walking. A new model is generated which is a beneficial type of locomotion as it helps them play faster and localizes them at points they should be. A new method has been introduced to design and learn about the CPGs in Nao robots that can learn trajectories in an offline mode and the trained parameters are transferred to an online controller. In case of crashing, the robot will have to stand up and resume playing again resulting in loss of time [15].

Emotional walking for humanoid avatars using brain signals was clearly described by **Ahmad Hoirul Basori**. He shows that instead of using the conventional camera tracking, gloves, ability to speak and brain interfaces to control facial expression, this paper has come up with a new multimodal interaction control which involves combining brain signals, facial muscle tension recognition and glove tracking to change the expression accordingly with the user's emotional condition. The emotion intensity is controlled using the glove and signals from brain activity and muscle movements are used as the emotional stimulator. The need to change the facial expression or walking power can be determined by the multimodal interface. Humanoid avatars have various patterns of walking and facial expression when stimulated by the user with different emotions as shown in the results. Faller, J, et all (2010) have proposed a brain interface which can be used by both the disabled and non-disabled people alike. Brain signal used provides a fast information transfer rate. Motion planning helps robots to move intelligently, some algorithms such as the hierarchical memetic algorithm have been used. However, this paper by Basori focuses on walking behaviour based on emotional condition rather than motion planning. Wang et al said two problems faced in creating a virtual human are- first, the construction of emotion and second, the generation of the affection model created to improve their presentation. Current 3D models lack believability. Melo and Paiva (2007) used shadow, light, composition and filter for conveying characters' emotions. The facial expression coding system by Ekman consists of six basic emotions- anger, joy, sadness, fear, disgust, surprise. The Nia mind controller is used to recognize and analyse brain activity signal and will produce a classifying signal based on the emotional condition. Nia consists of the following sensors:

1) Glance sensor
2) Muscle sensor
3) Alpha 1, 2, 3 and Beta 1, 2, 3. [16]

Brain signals can also be used for sophisticated interaction with the environment as demonstrated by **Bell** *et al.* Using brain signals obtained through electroencephalography (EEG) a humanoid robot can be controlled. EEG is normally regarded as an unlikely option to control complex objects owing to its low signal-to- noise ratio. This experiment shows interface based on EEG can be used to perform complex tasks such as walking and picking up objects. With the use of a dynamic image-based BCI, the proposed system can incorporate newly discovered objects and interactions in the environment with ease. This reduces the work of the user from having to exercise control at a low level, allowing the EEG signals to be used as control signals. Results from the nine user study showed that a command for the robot is selected from 4 possible choices in 5s with an accuracy of 95%. The results also demonstrates that EEG based BCI can be used for more sophisticated robotic interactions, which not only involves navigation but also manipulation and transport of objects. "Motor imagery will require much more training data and subject training time. The P300 used suffers from a limitation – control is coupled to stimulus presentation." [17]

Today, robots with torque controlled capabilities are readily available with great celerity, torque controlled algorithms for exploring such capabilities are exceedingly required. These algorithms offer some levels of compliance as well as high motion performance. In addition, they directly control contact interactions with the environment. Recent contributions in relevance to the torque controlled balancing approaches try to regulate Centre Of Mass(COM) position of the robot ensuring that the robot does not fall even when contact forces are physically admissible. Recently, Lee and Goswami proposed to control both the COM motion and the angular momentum of the robot. **Alexander** *et al.* propose a reformulation of momentum based balance controller that was initially proposed by Lee and Goswami. This formulation was advantageous as it guaranteed that the control would satisfy any constraint in contact forces, joint accelerations and torque commands. The formulation led to an interesting insight into how equation of motion can be decoupled to greatly simplify the design based on the entire robot dynamics. Finally, balancing experiments on a torque controlled humanoid robots were presented. The experiments were done on the lower part of the Sarcos humanoid robot. The angular velocities, linear accelerations and the orientation of the robot in an inertial frame were measured. A torque feedback controller was implemented to ensure that each joint produced the desired force generated by the balance controller. The balancing performance of the sarcos humanoid was tested in various different scenarios where external forces were applied. The optimization problem was significantly reduced by using the decoupling equations of motion as it helped to realise that the contact forces and the torque commands were redundant. The great advantage of this formulation is that it solves a single optimization problem instead of several ones and can therefore guarantee that the control law will be consistent with all the constraints (joint limits, acceleration, torque saturation, centre of pressure limits and contact force limitations). An interesting aspect of this implementation is that it was a pure torque controlled implementation without any joint space position control, which is still rare in pragmatic implementations. Since it was consistent with the equation of motion no trade-offs were necessary [18].

Dynamic balancing is important to a humanoid robot but when room-awareness features are added it takes the robot to a new level altogether. Without internal sensors such as a compass, humanoids lose their orientation for a fall. Re-initialization is difficult due to symmetric manmade environments. With the results of psychological experiments, the room awareness module proposed here improves self-localization strategies by matching and mapping visual background with color histograms. The matching algorithm generates confidence values for various possible poses. The robot's controller uses this confidence value to converge the most likely pose and prevents the algorithm from getting stuck in local minima. Experiments conducted by show that the geometric structure of a room has a very strong influence on the re-orientation capabilities of a humanoid robot. Lee et al proved that this impression of a room can be changed by using printed 2D shapes on walls suppressing the subjective geometric compressions. This approach was integrated through the mapping of the visual background of the robot surroundings beyond the known field. Colour histograms are used to keep track of the robot's orientation as separate module. The robot's controller uses the confidence values with 3 simple commands- flip pose, purge reflection and reset orientation. The main idea of this approach is to identify outstanding features and map them using self-localization and mapping approaches. The following sub-modules are needed in order to realise the room awareness approach:

1) Perceived colour histograms and background tiles.
2) Background model
3) Background evaluation
4) Confidence values.

To measure this approach improvement on a system without a room awareness module, two test scenarios were used on a simulated and real robot. Self-localization was initiated with the opposite incorrect pose and the sides were interchanged after half the trials. In the first test, the robot was allowed to move only its head and in the second one, the robot had to walk from one penalty position to the other and vice versa based on its localization. The real robots gave smoother confidence values than the simulated one. This shows that the room awareness improves the existing self-localization algorithm. The issues related to this paper are very open. Some of them include the optimal count of histograms, a different feature for modeling environment and virtual wall shape used. Implementation of optical search patterns forced the robot to look at areas with the most distinctive background [19].

Exploratory gaze movements use the fundamental idea of gathering relevant information regarding partner-social interactions. A humanoid robot was made, which could contextually estimate the target position of the partner's hand during the observation of partner's reaching movement. This was done actively gazing around the environment with the main aim of improving the collection of information for the task. It was seen that active gaze control provides an advantage in relevance to other perception approaches, both estimation precision and time required to recognize an action. Task-specific information plays a very important role in gaze control and the influence of low-level image statistics is minor. With the introduction of active vision, limitations of classical vision paradigm were overcome as formulated by Marr. The main problems still faced by the perception of dynamic events are "timely detection of relevant elements and recognition of discriminant dynamics." It is very important to not only recognize an event but also anticipate in, giving time to prepare and execute a response action plan. Directing attention to multiple candidates is a circular problem as i) to recognize an event, it is necessary to perceive the changes ii) to perceive these objects, it was necessary to direct the sensors iii) to direct sensors, the set of candidate objects and their trajectories. Concepts with hierarchical multiple models were used for execution and recognition (HAMMER) for action perception and imitation based on the 'direct matching hypothesis.' The use of gaze controller and HAMMER framework, helped in directing attention in order to maximize discrimination performance, maintaining the robustness and an estimation of both end effector location and position of all potential targets. The model was implemented on the iCub simulator where the robot head was controlled by their attention system. To study the role of active gaze control, different configuration models in different environment configurations were compared- ideal VAC, real VAC and no VAC. Also, the proposed system was compared with different attention controllers under different levels of gaze-independent noise-discriminative model, no VAC, Random, Round Robin allocation, Maximum Effector and Entropy. Under medium level of noise entropy had the maximum performance and under high level of noise no VAC had the maximum performance. The results showed that the proposed approach is a viable solution for the action recognition problem in unknown environments. Uncertainty of targets for some actions is higher and thus the action plans used to counter this will have to be complemented by initial exploratory stage [20].

Zero Moment Point (ZMP) is related to dynamics and control of legged locomotion and it therefore becomes an important issue to discuss. The paper by **Vukobratovic** *et al*. employs two methods. First it introduces the notion of dynamic balance important for the tasks realization by humanoids. ZMP was given a lot of importance as it is the most important indicator of robot dynamic balance. The scientists before Bernstein studied human motion with the objective of describing it whereas Professor Bernstein was the first in world science to study motion to establish how it was controlled and from the viewpoint of knowledge of regularity of brain functioning. The ZMP was the most important bio-inspired notion involving biped locomotion. The WL12 performed fully dynamic walking. The most important issue is the maintenance of a humanoid upright position. To achieve the pre-set goals a unique and bidirectional correspondence must exist between the movements in joints and external effect related to the environment. The contact force between ground and the foot is unilateral and it is therefore important that the biped does not generate any forces causing the turning of the foot about its edges. In a single-link foot, the whole foot is the terminal link while with the two-link foot only toes' link is considered terminal. The whole body relies on a single support phase while the both the feet are in contact with the ground in the double support phase. The turning of the foot in the single support posture meant that the posture was compromised whereas it is much more flexible with the double support posture. The deviation of ZMP from its reference position is caused by the deviation in tracking reference trajectories at the joints. The reordered movement changed from start to end; therefore it was impossible to control the system in the same way during the whole movement. Hence, the movement was split into 3phases having different characteristics. The agile motion of the whole body is characterized by phase 1. The main aim is to prevent the fall by preserving the dynamic motion. The occurrence of the disturbance marks the beginning of the phase ending with the CM projection and comes down closer to the ZMP position. "The "calming down" phase is phase 2, which lasts until the deviation of the instantaneous ZMP position from its reference reaches less than 0.001M". The system returns to the "normal position" of standing on one (left leg) in phase 3. Modeling of complex mechanical systems, dependence on posture and appropriate modeling were the difficulties faced in employing ZMP dynamic balance [21].

It is a challenging task to develop balancing and posture correction algorithms for stable walking motion. Bipedal locomotion requires stable position control with effective sensory feedback. This feedback system is presented by **Wee** *et al*., in order to minimize the modeling errors and disturbances also to introduce an alternative approach in generating a stable Centre-of-Mass (CoM) trajectory by using an observer-based augmented model predictive control technique with sensory feedback.Augmented Model Predictive Control (AMPC) algorithm is applied with an on-line time shift. To helpthe system track the desired Zero Moment Point (ZMP) as closely as possible and at the same time to limit the motion jerk, minimizing of the cost function is done to process future data to optimize a control signal. Force sensors are fitted in the robot's feet to measure the contact force's location.An observer is also used into the system. Adaptability, robustness and stability are still a few factors that make the controlling of a robot, a difficult task. The Linear Inverted Pendulum Model (LIPM) and the Zero Moment Point (ZMP) methods are the most common approaches. A non-minimum phase system is the problem with the LIPM method as it produces a undershoot response to a step input. This undesired effect is compensated for by a new observer-based Augmented Model Predictive Control (AMPC) method. "Together with the sensory feedback system, this method reduces the jerk produced by the ground landing impact forces and is also able to improve the overall system performance of ZMP tracking under external disturbances. The effectiveness of the proposed scheme is demonstrated in a simulation and in comparison with the preview control method." TPinokio robot along with having 25 DOF is constructed with light-weight aluminum material. A compact joint-housing mechanism is used. This can be modeled as a "Point-mass" system as it is a simple kinematic structure. To be able to measure the ZMP location, the robot's feet are fitted with force sensors. The system tracking error can be determined from the ZMP value. A feedback signal is sent to the observer to improve the system stability. This intelligent sensory system is employed at strategic location on the robot. The proposed AMPC model is an augmented state-space model with an embedded integrator. A comparison is done with the preview control method and it is found that in comparison with the preview control technique, the controller tries to reduce the jerk and impact force during swing foot landing to cautiously reduce the ZMP error. Thus, during the double support phase (DSP), the weight of CoM transfers from the supporting foot to the landing foot (new supporting foot). Optimization process does not need to solve the Riccati equation and the optimization window can be easily adjusted to fine-tune the system response are some of the other advantages of using the AMPC model. Since a recursive iteration method, with continuing improvement in computer hardware and software architecture is used in the AMPC it reduces system-processing time and therefore, it is possible to implement it in AMPC real-time. By using a high-speed computer, it is possible to implement the control algorithm with on-line updates close to real-time with a trade-off in sampling and update rate [22].

A few contributions revolutionized locomotion in humanoid robots. One such addition was by **Evan H Pelc** *et al*. they decided to test the ability of a neural oscillator; a simple hopping robot controlled by an artificial neural oscillator was used. "The robot had a single joint, actuated by an artificial pneumatic muscle in series with a tendon spring. Two neural control parameters - descending neural drive and neuromuscular gain were used to examine how the oscillator robot system responds to the variations. Also, to test the ability of the oscillator-robot system to adapt to variation in mechanical properties, series and parallel spring stiffness were changed. At the resonant half-period for the stance phase, the neural oscillator drove the system consistently and adapted to a new resonant half-period when the muscle series and parallel stiffness were changed. "Elastic energy in the tendon has accounted for 70-79% of the mechanical work done during each hop cycle." The stance phase needs the maximum muscle force and work for the body motion. Long tendons like the Achilles tendon in human, plays a very important role in storing and returning elastic energy during bouncing gaits. The robot was designed to represent general aspects of lower limb mechanics during human hopping. It consisted of wooden foot and shank segment with one degree of freedom to represent a simplified ankle. To record segment and joint kinematics an eight camera motion analysis system was used. Hopping frequency, stance duration and aerial phase duration was determined from the ground reaction force data. Results from the experiment showed that the hopping dynamics were determined by intrinsic properties of the mechanical system, and not by the choice of neural oscillator parameters. The findings from the experiment also give evidence that the artificial neural oscillator drives a hybrid dynamic system at partial resonance [23].

Victor Santos *et al*., in their paper say that research in the field of humanoid robotics imply prohibitive costs. The research mainly aims at performing activity on dynamic balance, sophisticated sensory motion control or cognitive activities. On the other hand, recent innovations and technologies have led to building of robotic platforms that mimic the kinematics and kinetics of human beings. The main challenge is to balance the need for human-like behavior with the reality of the current technology openings today with respect to materials, actuators, motor control, sensors and computation power, as well as with factors such a reliability, cost and availability. The main challenge is to balance the need for human-like behavior with the reality of the current technology openings today with respect to materials, actuators, motor control, sensors and computation power, as well as with factors such a reliability, cost and availability. The main goal of the project was to develop energy-efficient humanoids with standard components and open software, and also of energy-efficient actuation systems, novel complex networks of sensors and multi-sensor data fusion algorithms, and intelligent distributed and local processing. In order to achieve these goals, the initial work was supported by the following design principles: (1) hybrid actuation; (2) multiple sensors; and (3) distributed control architecture. The author aims to combine the strengths of active actuation in terms of versatility and the advantages of passive mechanisms for dynamic walking robots, to exploit hybrid actuation in order to construct a novel platform for these humanoids. “The focus of our research is the current challenge of embodiment that implies to change the paradigm from the human-like outer shape to more human like principles in perception and locomotion,” says Santos. Joint transmission that switch between drive and free modes to explore ballistic motions, knee bending limitation and a compliant foot with a passive toe joint, were the essential features that were focused on from the design point of view. The lower limbs consisted of the articulation of the plantar portion of the portion of the foot, the ankle, the lower leg, the knee, the leg and the hip. To achieve the required degrees of freedom, “a three orthogonal rotary axes joint, following the design applied in the ankle and hip joints, is used in the connection between the hip section and the upper section of the chest assembly.” The upper limb section included the shoulder, the elbow and the wrist joints. The degrees of freedom required for the humanoid neck is to support the functions of vision and auditory systems and must therefore, resemble the pan and tilt movements. With regard to the hybrid actuation, the main result was the enormous reduction in the torque extreme requirements as well recovering energy by the use of the passive element. Standalone operations which includes independent and self-contained tasks, was now possible in a distributed architecture in which the control, vision and auditory capabilities were enhanced. Additional research is needed, if the proposed design features are ill-suited [12].

III. Future Work

This review also helps in providing options for future research in locomotion. CPG can be used for more sophisticated and complex mechanisms. Also, under the presence of obstacles and in dynamically changing environment feedback can be left out to walk in 3 dimensions without any support structure [14]. CPG, if used efficiently and in an effective way can boost the locomotion in humanoids to a great extent. Identifying the minimal neuromechanical system is necessary to achieve stable forward bouncing locomotion [23]. As we know, stable walking motion needs effective gait balancing and robust posture correction and this indeed is a very challenging task. To overcome this challenging task, combining discrete-time AMPC with the Laguerre function and the observer is important as it will help in enhancing and enhancing the tracking algorithm to reduce the effect of the undershoot water-bed phenomenon [22]. Looking at controlling the locomotion in a humanoid, it is seen that EEG based BCI is a more accurate way to control more sophisticated robotic interactions than other controls [17]. Thus, focus should be on BCI so as to improve the way humanoid locomotion is controlled. Various aspects of locomotion such as the ZMP should also be given importance as it will only result in better locomotion. There are other aspects of locomotion that have not been discussed in this paper and can/will improve locomotion.

IV. Conclusion

Technology has brought imagination to life in the last few decades. Humans have been enthralled with the possibility of robots that act and look just like them. The application of Humanoids is increasing by the day. However, it hasn’t been implemented to nearly all aspects of human life. If research is done to improve the locomotion mechanism of Humanoids, factors such as energy, cost and efficiency can be improved by prodigious amounts. Thereby, making the humanoids more affordable and allowing them to render their services to all forms of human life. With the approaches such as the room-awareness module and the exploratory gaze movements being employed, humanoid robots have become independent; self-learning how to react to dynamically changing environments and retaining what is learnt. Emotional Walking adds more realism, thus bringing them closer to their human counterparts in the way that they express emotions. Just like human beings’ interact with their social counterparts, they will now be able to communicate, relate to and even work in a more dynamic environment with these humanoid robots. CPG-an important aspect to the locomotion mechanism, is optimized with the use of the Gaits Algorithm which improves parameters like the internal connectivity structure and feedback pathways, thereby increasing the efficiency and effectiveness in humanoids. The ZMP method calculates the point at which all the momentums converge to zero which helps in understanding the dynamic balance in a humanoid. However, the locomotion mechanism has not been improved to a great extent as attention has been majorly paid to finding factors of little relevance; that could improve energy efficiency of humanoids very minimally.

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