Comparison of Artificial Neural Networks based on Controllers for Biped Robots

Nada Masood Mirza

Al Ain University, Al Ain, United Arab Emirates

***Abstract* - This paper provides a brief overview the need for humanoid robots specifically bipedal robots. The advantages and shortcomings of bipedal robots have been highlighted. The paper discusses in detail the various types of controllers that have been applied for the control of humanoid robots. Typical controllers such as slide mode control, active force control, computed torque control etc., require the boundaries of uncertainties to be known, which is very difficult considering the real world terrain. The application of artificial neural networks has thus become a priority in controller design for bipedal robots. Some of the neural network based on the controller design and their comparisons to typical controllers have been surveyed in this paper. The survey presented visibly shows that the application of neural networks results in an exponential increase in accuracy for bipedal robots in comparison to classic approaches.**

***Keywords* - Artificial Neural Networks, Humanoids, Biped Robots.**

1. Introduction

In the recent era technical contributions are pertaining to the control the configuration of robots, which have witnessed an exponential increase because they are widely used in many engineering applications, such as space exploration, under water survey, industrial and military industries and medical applications and so on [1].

DOI: 10.18421/TEM84-24
https://dx.doi.org/10.18421/TEM84-24

Corresponding author: Nada Masood Mirza,
Al Ain University, Al Ain, United Arab Emirates
Email: *nada.mirza@aau.ac.ae*

Received: 26 August 2019.
Revised: 18 October 2019.
Accepted: 25 October 2019.
Published: 30 November 2019.

Many efforts have contributed towards developing various kinds of robots such as constrained robots, humanoid robots, mobile robots and so on. According to some roboticists, humanoid robots provide more interface while compared to the mechanistic robots. Owing to the inherent advantages of humanoid robots, research community has taken a keen interest in the control of such robots. Humanoid robots can be further classified into biped robots and bimanual robots. Biped robots are the ones with two pedals, the same like human beings, while bimanual robot has two hands.

The control of biped robots is difficult task which requires the application of well-designed controllers in order to cater for the higher order dynamics involved. Furthermore, the external conditions are involved – terrain, human interaction etc., which also play a significant part in complicating the design of controllers for biped robots. The application of neural network on typical controllers assists in the robustness of the designed biped robots.

In this paper, we make a relatively comprehensive review of research progress on controlling different aspects of biped robots by means of various designed neural networks [1]. This paper includes a brief discussion on biped robots and their significance. The control problems of typical biped robots and the inherent deficiencies of typical controllers have also been highlighted. Some of the recent researches regarding the application of artificial neural network based controllers are discussed in detail.

2. Biped Robots

More than 50% of earth's surface cannot be accessed using conventional vehicles (wheeled/tracked) [2], [3]. But in cases of emergency rescues, natural disasters etc. it is imperative that alternative machines are developed. As of date such devices, which can travel on rough terrain, or assist people in hazardous working climates, are of very limited capability. From the field of robotics, biped robots have emerged as promising tools to solve the before mentioned problems. Furthermore, research on biped robots can also be employed to develop new rehabilitation tools in order to assist elderly people along with people with physical disabilities.

There are numerous applications of biped robots, some of which are shown in Fig. 1. [4]

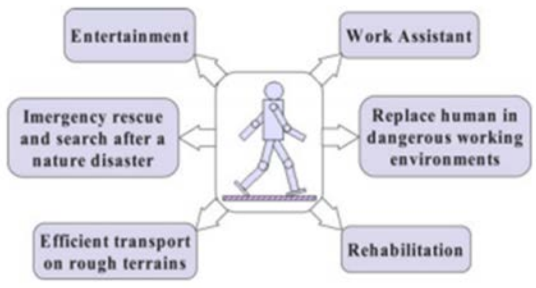

Figure 1. Applications of Biped Robots

Moreover, they have advantage of simpler moving mechanisms and very lighter weight due to relatively less number of actuators being used. Therefore, if the controls are developed with precision for these robots, their usefulness would be increased exponentially. Furthermore, due to their lightweight, the risk of damage to instruments and humans around them is very little [5],[6].

2.1. Control Problems

Despite the advantages of biped structure, it has its own share of shortcomings. Owing to the many degrees of freedom which are to be controlled under coupling effects along with nonlinear dynamics, walking on two legs is a demanding task. Since 1980's the extensive research has been carried out on control of humanoid walking robot with a number of researches proving very successful (Hirai et al., 1998, Sakagami, 2002, Kaneko et al., 2002, Kim et al., 2007, Hyon and Cheng, 2006, Ogura et al., 2006) [7]. The physical structure of biped robot is shown in Fig 2 [5].

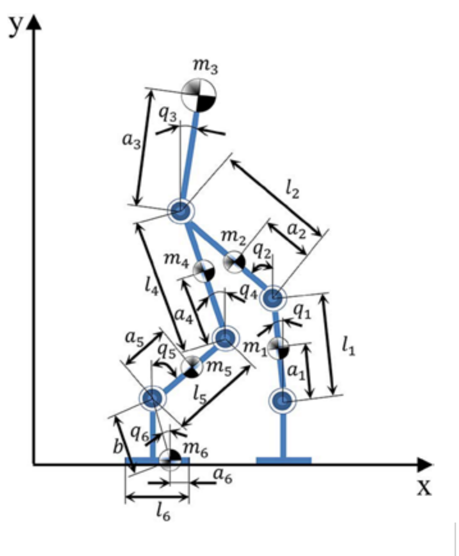

Figure 2. Physical structure of Biped Robot

Every now and then it's difficult to maintain the stability and control of the biped robot because they have a high order dynamic equation in addition to the different kind of terrains in the actual world and their gait has to be trained for various situations in present around. To solve all these problems numerous control techniques has been developed for example computed torque control (CTC), sliding mode control (SMC), active force control (AFC) etc. These methods require that the boundaries of uncertainties and disturbances must be known, which is difficult to predict in real life situation. For these reasons artificial neural networks are included in the implementation of biped robots [8].

3. Artificial Neural Networks

To make the humanoid robot more like humans and to replace them in industry and dangerous circumstances, research is being carried out focusing more on Artificial Neural Networks (ANN). Generally speaking, neural networks can be classified into different types according to different criterions. For example, in terms of the network structure, they can be classified into two categories: feedforward neural networks and recurrent neural networks (RNN). A feedforward neural network is an artificial neural network with no cycles or feedback signal inside, while a recurrent neural network allows bi-directional information flow, which means the information inside flows from a successive node to a previous one (or called feedback), or forms a closed cycle within a single node.

Artificial neural networks are able to mimic the working of some of the features of human nervous system, and they can learn to compute variable data, which is not the same for the data stored in them. The basic processing element of neural network is a unit which acts as a biological neuron, and it can do summation on the data received from one or more input channels. Processing element is shown in the Fig. 3.

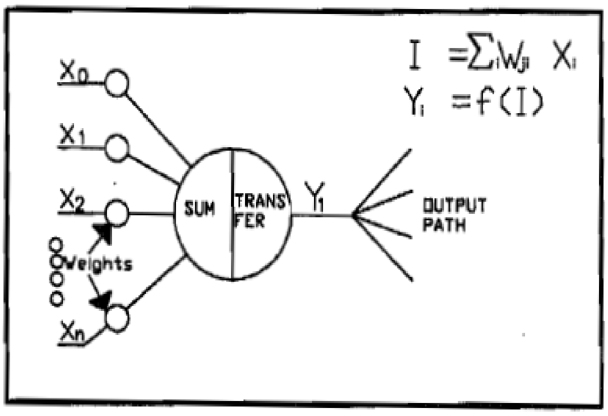

Figure 3. Processing Element of Neural Network

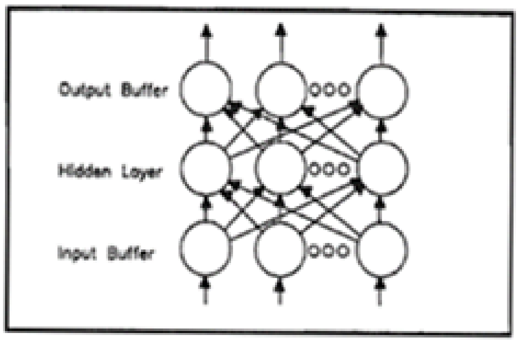

Figure 4. Layer Structure of Simple Neural

Generally speaking, numerous processing elements are joined together to form a neural network. Organization of these elements is done in the form of layers and two main functions are implemented in these which are learning and recall. Layer structure of simple neural network is shown in Fig.4 [9].

It's been more than a decade of the fact that research has been conducted to improve the working controllers with the help artificial neural network [10]. Different architectures of ANN are used to develop the control systems in the biped robots including Recurrent Neural Network (RNN), Wavelet Neural Network (WNN), Recurrent Wavelet Neural Network (RWNN), Recurrent wavelet elman neural network (RWENN) and Self-Recurrent Wavelet Neural Network (SRWNN). All of these have their own limitations and strengths, but the three most commonly used will be highlighted in this paper [9].

3.1. Self-Recurrent Wavelet Neural Network based controller

In early 2000 a robust controller was designed by Sin Ho Lee, Jin Bae Park and Yoon Ho Choi for Biped robot stable walking, using SRWNN and sliding mode control (SMC). Basic structure for the SRWNN is shown in Fig. 5.

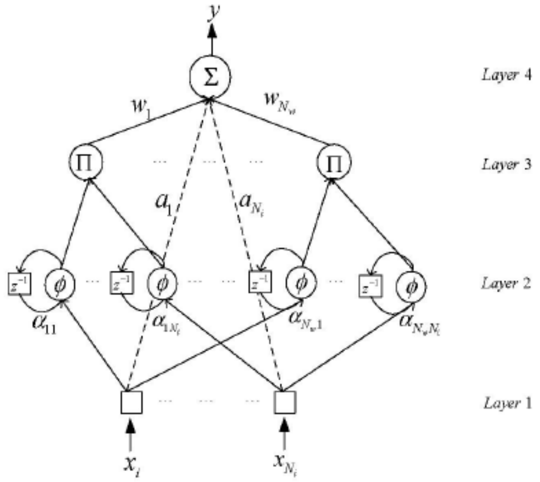

Figure 5. Basic Structure of SWRNN

According to the structure of the SWRNN there are four layers, layer 1 is input layer, layer 2 is considered as mother wavelet layer, product of the nodes in this layer join together to form layer 3 and then by the linear combination of nodes of layer 3, output layer which is at level 4 is generated. Control structure of the proposed model is given in Fig. 6.

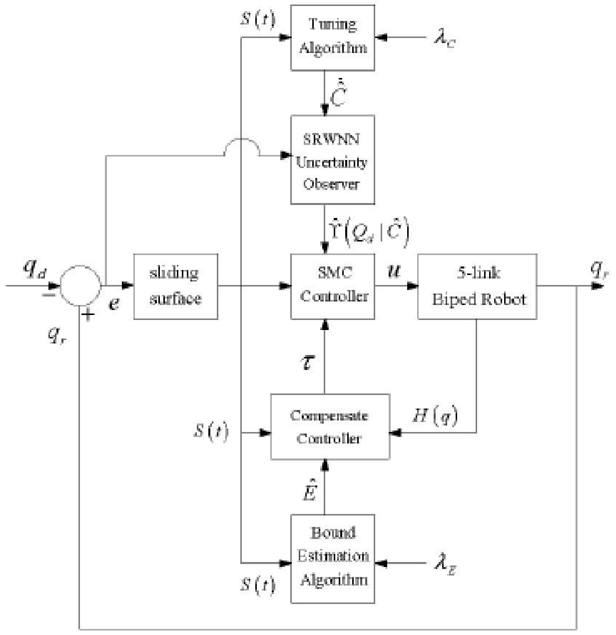

Figure 6. Proposed Model of Control Scheme

Further on, the comparison was conducted by using both SMC and SMC_SWRNN controller for the same Biped robot, and from the results it was verified that mean square error (MSE) for SMC was almost double the number of SMC_SWRNN. Comparative result for MSE of both cases is given in Table 1 [8].

Table 1. MSE comparison

	SMC	***SMC_SRWNN***
MSE of joint 1	*0.0036*	*0.0016*
MSE of joint 2	*0.0025*	*0.0011*
MSE of joint 3	*0.0014*	*00006*
MSE of joint 4	*0.0015*	*0.0007*

3.2. Recurrent Neural Network (RNN) Based Controller

In 2007 a hybrid controller was introduced by Wu Yilei, Song Qing, Yang Xulei which consisted of Proportional Derivative (PD) and RNN. The target of this design was to improve the response of a system in the presence of faults. Structure for the RNN is shown in Fig.7.

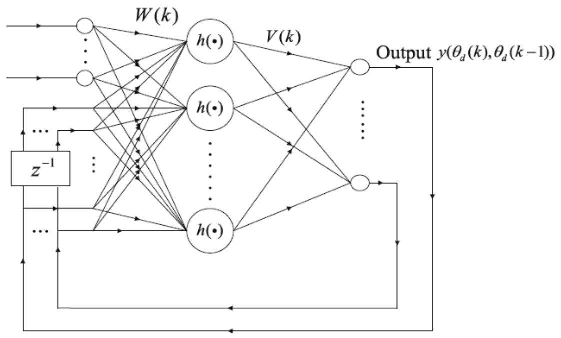

Figure 7. Structure for external feedback RNN

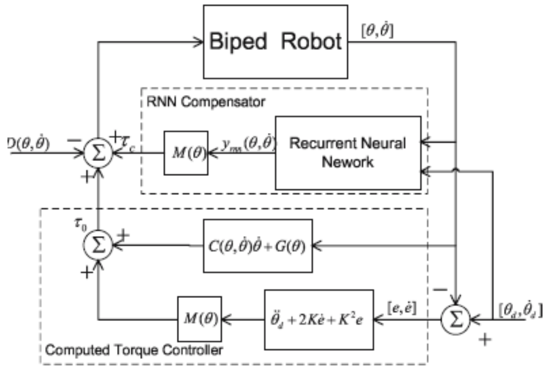

Figure 8. RNN Control Scheme

Simulations were run on PD controller and RNN_PD controller simultaneously, and it was observed that they both respond in the same manner in the absence of system faults, but after the occurrence of fault results were totally different and only RNN_PD was able to provide the compensation of nonlinear errors [11]. The results of the application of PD controller with and without RNN can be seen in Fig. 9. The results depict a visible improvement in accuracy with the application of RNN on simple PD controller.

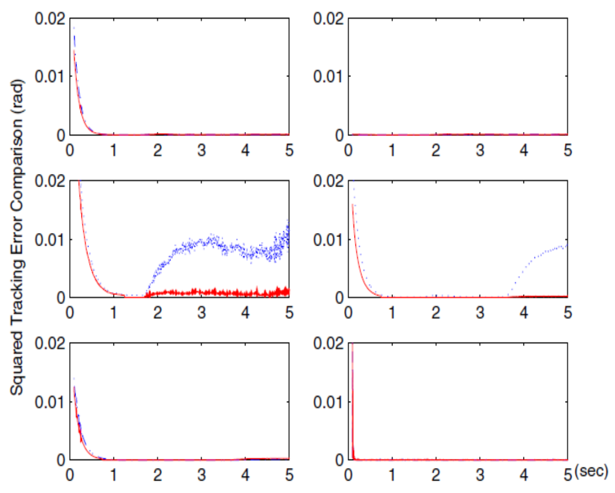

Figure 9. Squared Tracking Error in case of fault occurring (Red/ Straight line with RNN, Blue/ Dashed line without RNN) [11].

3.3. Recurrent Wavelet Elman Neural Network (RWENN) Based Controller

Recently in 2017 RWENN was introduced by Chih-Min Lin and Enkh-Amgalan Boldbaatar. RWENN works for accommodating the fault introduced by the system. In RWENN there is an input from a context layer which has the feature of self-feedback and an output recurrent layer to the hidden layer which increases the precision and time convergence of the network. The adaptive laws for REWNN are being derived from the Lyapunov theorem, and smaller networks are used to avoid the computational burden. Basic structure for RWENN is given in Fig. 10 [5].

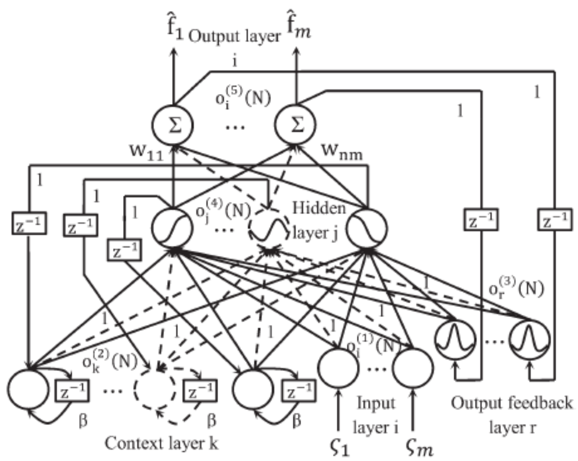

Figure 10. Basic Structure of RWENN

There are five layers which are being structured in RWENN namely input, hidden, context, output feedback and output layers. Comparison was held between different techniques for the accommodation control. It has been observed that despite the fact that RWENN has a slightly more execution time as compared to RNN based controller, RWENN based control scheme reduces the total root mean square error by more than 40% [5].

4. Conclusion

The development of humanoid robots has witnessed exponential growth in the last few decades. Despite the focus of research community in this field of robotics, there is a need for improvement. It is imperative to further enhance the capabilities of bipedal robots using innovative hardware as well as control software solutions. The application of such solutions will result in making robots adaptable to human environment in addition to becoming intelligent and autonomous. This survey depicts the inherent drawbacks of the application of typical control techniques for bipedal robots, which are meant to operate in real life human environment. Only through the appropriate application of intelligent control methods, bipedal robots can be controlled in a robust manner. This survey visibly demonstrates the application of neural network based on the strategies, comprising existing controllers' results in a visible improvement within the accuracy and stability of bipedal robots.

References

[1] Jin, L., Li, S., Yu, J., He, J. (2018). Robot manipulator control using neural networks: A survey. *Neurocomputing, 285*, 23-34.

[2] Anon, (1967). Logistical vehicle off-road mobility, *U.S. Army Transportation Combat Developments Agency, Fort Eustis, Virginia, Tech. Rep., Project TCCO* 62-5.

[3] Bekker, M. G., (1969). Introduction to Terrain Vehicle Systems. *Ann Arbor, MI: Univ. Michigan Press*.

[4] Wang, S., Chaovalitwongse, W., Babuska, R. (2012). Machine Learning Algorithms in Biped Robot Control. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 42*, 728-743.

[5] Lin, C.-M., Boldbaatar, E.-A, (2017). Fault Accommodation Control for a Biped Robot Using a Recurrent Wavelet Elman Neural Network. *IEEE Systems Journal*, *11*, 2882-2893.

[6] Ito, S., Nishio, S., Ino, M., Morita, R., Matsushita, K., Sasaki, M, (2018). Design and adaptive balance control of a biped robot with fewer actuators for slope walking. *Mechatronics, 49*, 56-66.

[7] Yılmaz, M., Seven, U., Erbatur, K., (2010). Biped Robot Walking Control on Inclined Planes with Fuzzy Parameter Adaptation. *IFAC Proceedings Volumes 43*, 288-293.

[8] Lee, S. H., Park, J. B., & Choi, Y. H. (2006, October). Sliding mode control based on self-recurrent wavelet neural network for five-link biped robot. In *2006 SICE-ICASE International Joint Conference* (pp. 726-731). IEEE.

[9] Aylor, S., Rabelo, L., Alptekin, S., (1992). Artificial neural networks for robotics coordinate transformation. *Computers & Industrial Engineering, 22*, 481-493.

[10] Scott, G.M., Shavlik, J.W., Ray, W.H., (1992). Refining PID Controllers Using Neural Networks. *Neural Computation, 4*, 746-757.

[11] Wu, Y., Song, Q., Yang, X., (2007). Robust Recurrent Neural Network Control of Biped Robot. *Journal of Intelligent and Robotic Systems, 49*, 151-169.