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Lower Limb Rehabilitation Robotics System Based on BP Neural Network

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Abstract

This research explore a robotic system based on neural network used for therapy of foot drop case, which caused by stroke. This device supports most exercises should be practiced by patient at any time or any place no need going to the hospitals. I had built robotic on mechanism of parallel robot which is controlled by microcontroller ATM mega 2560. The robot allows people who need to do the exercise without need for outside help. Many theoretical and experimental testing had made on proposed prototype do the particular medical therapy. Results show that the accuracy in path and angle was lower worst case for each exercise, which is good according therapy point of view.

Keywords: Artificial neural network , lower limb, brain stork , rehabilitation , BP neural network

INTRODUCTION

The concept of Neural Networks were inspired from biological nervous systems of human being Artificial Neural Networks (ANN) are calculative models for pattern recognition and machine learning . It is simple way for operate parallel elements that introduced to the Networks. The functions of ANN Artificial Neural Networks are greatly depended on the connections between parallel elements so anyone can adjust the connections of elements to accomplish a particular function. The process of modifying of connections are called learning of Artificial Neural Networks . so that a specific input/targets the Artificial Neural Networks can be trained to get outputs of the network that match or equal the targets.. The NN will be already trained for comparing the output and target and supplying information during that until output and target will be matched.

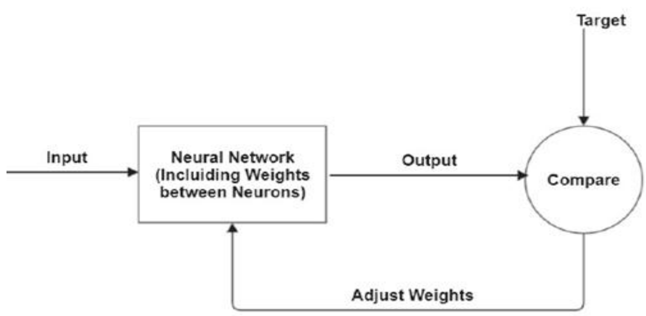

Figure 1: Neural Network block diagram

LITERATURE REVIEW

Abdul-Basset A. AL-Hussein (2017) A composite PD and sliding mode neural network (NN)-based adaptive controller, for robotic manipulator trajectory tracking, is presented in this paper. The designed neural networks are utilized to sacrificial the robotics nonlinearities , also make more it effective this will improve the functionality of filtering errors depending on PD and sliding controller of neural system . the theorem used to establish system stability was Lyapunov theorem the pursuing error limitedness. The enhance Lyapunov tool is used to derive the neural network weights updating law. Erhan AKDOGAN (2016) . a lower limb rehabilitation robot was modeled and controlled for upper limbs. The ret rotted robot system is able to do, active, active-assistive and passive curative exercises. On the other side , it work as active-assistive exercises by muscular activation. A network – established on human machine interface, which can support self-care, was created to control the robotic system. The robotics system interface contains evaluation unit, are not able to use only torque and ROM, but also muscular activation of patients for the estimation results. The, estimation and therapy can be perceived by a system for both lower and upper limbs using parameters such as ROM, generated muscular activation, and torque of the limbs] . Erhan Akdog˘an & etal (2011) . They use three degrees of freedom therapeutic exercise robot and demonstrate design and control of robot used in therapy for patient that required rehabilitation after a muscle disorder , spinal cord injury stroke , a surgical operation, or SCI. for controlling robot, a ‘‘Human–Machine Interface’ with a rule-based control structure was developed. The robot can perform all passive and active exercises as well as learning ability of specific exercise without the physiotherapist by using Human–Machine Interface. Further , if a patient interact against robot's manipulator during exercises , the flexibility of manipulator change the position depend on feedback data. This benefit of manipulator flexibility will serve therapeutic exercise and physiotherapist in terms of motion capability. Chen JIA (2015) in This study feasibility of new a model to characterize nonlinearity of mechanical impedance of the ankle within a particular range of frequency and the root mean square (RMS) value of the Electromyography of muscles of ankle by using ANN. A lower limb rehabilitation robot Ankle bot was used to apply dummy -random mechanical disturbance to the ankle and explore the angular displacement of ankle to assessment data of mechanical impedance for ankle. Meanwhile, the surface Electromyography signals from the chosen muscles were observed and recorded. in this research final ANN models are built or constructed for two degrees of freedom . The results of analysis of the ANN model showed the feasibility of developing models with adequate accuracy and to define the mechanical impedance of the human ankle in terms of lower extremity muscles' EMG statistical properties.

STRATEGY PHYSICAL THERAPY

The training are the backbone of treatment for people had foot drop caused by stoke . The benefit of training contain decrease spasticity, and increasing ability of muscle . The training are classified according to foot motion Kazem & etal :

class 1 & 2 : the patient will sit and contacting heel's edge to the table then trying rotate the ankle CW or CCW (roll motion) angle and then back to neutral position as shown in Figure (2). Do it ten times and then revers the operation Figure (2).

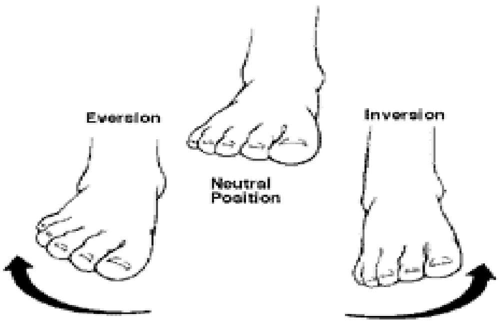

Figure 2: Exercises 1 and 2

class 3 & 4 : the patient will sit and contacting heel's edge to the table "then trying translate the ankle up or down angle and then back to neutral position as shown in Figure (3) Do it ten times and then revers the operation.

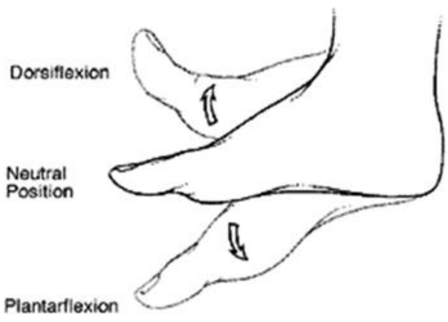

Figure 3: Exercises 3 and 4

Class 5 & 6 : the patient will sit and contacting heel's edge to the table then trying rotate the ankle CW or CCW (yaw motion) angle and then back to neutral position as shown in Figure (4). Do it ten times and then revers the operation. Do this exercise ten times a day.

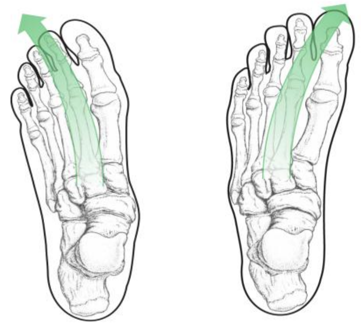

Figure 4: Exercise 5 , 6

A base Cartesian coordinate frame XYZ is fixed at the center of the base platform with the Z-axis pointing vertically upward and the X- axis pointing towards the ball joint $\boldsymbol{B_i}$ **.** Similarly, a coordinate frame xyz is assigned to the center of the upper platform, with the z- axis normal to the platform and the x-axis pointing towards the ball joint $\boldsymbol{P_i}$. Hence, the coordinates of the pin joints in XYZ frame are

$$B_1 = \begin{bmatrix} R \\ 0 \\ 0 \end{bmatrix} \quad B_2 = \begin{bmatrix} \frac{-1}{2}R \\ \frac{\sqrt{3}}{2}R \\ 0 \end{bmatrix} \quad B_3 = \begin{bmatrix} \frac{-1}{2}R \\ \frac{-\sqrt{3}}{2}R \\ 0 \end{bmatrix} \quad \ldots\ldots\ldots\ldots (1)$$

$$p_1 = \begin{bmatrix} R \\ 0 \\ 0 \end{bmatrix} \quad p_2 = \begin{bmatrix} \frac{-1}{2}R \\ \frac{\sqrt{3}}{2}R \\ 0 \end{bmatrix} \quad p_3 = \begin{bmatrix} \frac{-1}{2}R \\ \frac{-\sqrt{3}}{2}R \\ 0 \end{bmatrix} \quad \ldots\ldots\ldots\ldots (2)$$

The position of the center of moving platform is

$$P_0 = \begin{bmatrix} 0 \\ 0 \\ h \end{bmatrix} \quad \ldots\ldots (3)$$

when h is the hight of moving platform respect to the base.

Inverse Kinematic of system

The coordinate frame ***xyz*** of the ball joint for the link with respect to the base frame ***XYZ*** can be described by the inverse kinematic homogeneous transformation $\boldsymbol{T_x}$ Tsai,L. W. (1999)

$$T_x = \begin{bmatrix} & R_b & & \begin{matrix} 0 \\ 0 \\ h \end{matrix} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \ldots (4)$$

When the matrix R is a (3x3) rotation matrix and it is

$$R_b = R_{X_P}(\alpha) \,.\, R_{Y_P}(\beta) \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where $R_{X_p}(\alpha)$, $R_{Y_p}(\beta)$, and $R_{Z_P}(\varphi)$ rotation matrices Tsai, L. W. (1999)

But

$$R_{X_P}(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\alpha & -Sin\alpha \\ 0 & sin\alpha & cos\alpha \end{bmatrix} \quad \ldots(6)$$

$$R_{Y_P}(\beta) = \begin{bmatrix} cos\beta & 0 & sin\beta \\ 0 & 1 & 0 \\ -sin\beta & 0 & cos\beta \end{bmatrix} \quad \ldots.(7)$$

$$R_{Z_P}(\varphi) = \begin{bmatrix} cos\varphi & -sin\varphi & 0 \\ sin\varphi & cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \ldots(8)$$

The rotation matrix is defined as [36]

$R_b = R_{X_P}(\alpha) \,.\, R_{Y_P}(\beta) =$

$$\begin{bmatrix} cos\beta & 0 & sin\beta \\ sin\alpha\, sin\beta & cos\alpha & -sin\alpha cos\beta \\ -cos\alpha sin\beta & sin\alpha & cos\alpha cos\beta \end{bmatrix} \quad \ldots(9)$$

The position of the mobile frames for rotating by α and β can be represented by the homogeneous transform matrix T.

$$T = \begin{bmatrix} cos\beta & 0 & sin\beta & 0 \\ sin\alpha sin\beta & cos\alpha & -sin\alpha cos\beta & 0 \\ -cos\alpha sin\beta & sin\alpha & cos\alpha cos\beta & h \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad ..(10)$$

The Cartesian position of the ball joints with respect to the base frame ***XYZ*** can be expressed as Tsai, L. W. (1999)

$$\begin{bmatrix} P_i \\ 1 \end{bmatrix} = [T] \begin{bmatrix} p_i \\ 1 \end{bmatrix} \quad \ldots\ldots. (11)$$

Where the vectors ***Pi*** and p_i characterized by the position vectors of the i_{th} ball joint with respect to the ***X Y Z*** and upper frame ***xyz,*** respectively. The length of the link, which is equal to the distance between the i_{th} ball joint on moving platform and base

$$.D_i = P_i - B_i = d_i . S_i \quad \ldots..(12)$$

Where D_i is the link vector, d_i is the link length, S_i as a unit vector along the longitudinal axis of the *i*-th link and

$$S_i = \frac{D_i}{\|D_i\|} \quad \text{and} \quad d_i = \|D_i\|$$

The length of the actuators during the first four exercises will be change as explain in Table (1).

Table 1. The practical actuators length with exercises.

Exercise No.	Actuator 1		Actuator 2		Actuator 3	
	Length (mm)	Change (mm)	Length (mm)	Change (mm)	Length (mm)	Change (mm)
0	0.3027	-	0.3027	-	0.3027	-
(1)	0.3027	0	0.3357	33	0.2697	-33
(2)	0.3027	0	0.2787	-24	0.3267	24
(3)	0.2297	-73	0.3387	36	0.3387	36
(4)	0.3487	46	0.2797	-23	0.2797	-23

Differentiating the expression in (12) gives the velocity relations as Schilling, R. J. (1996)

$$d_i w_i \times s_i + \dot{d_i} s_i = w_p \times p_i$$

We can get linear velocity by multiplying dot product with s_i as:

$$[\dot{D}] = (p_i \times S_i) \begin{bmatrix} \dot{\alpha} \\ \dot{\beta} \\ 0 \end{bmatrix} \quad \ldots.. \quad (13)$$

$$[\dot{D}] = [J]^{-1} \begin{bmatrix} \dot{\alpha} \\ \dot{\beta} \\ 0 \end{bmatrix} \quad \ldots\ldots(14)$$

Where $\dot{\alpha}$, $\dot{\beta}$ is the angular velocity about x and y axis respectively as Figure (5) The linear velocities of link can be represented as :

$$[\dot{D}] = \begin{bmatrix} \dot{d}_1 \\ \dot{d}_2 \\ \dot{d}_3 \end{bmatrix} \quad \ldots\ldots..(15)$$

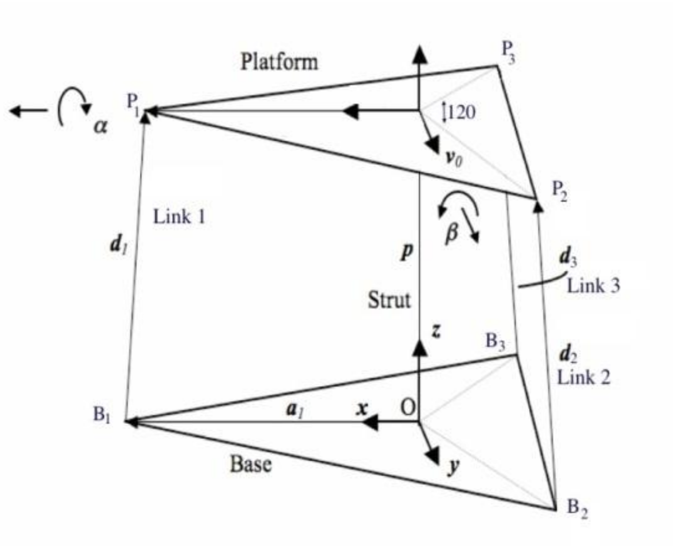

Figure 5. Geometry of the actuated parallel manipulator

Training robotics systems BP neural network algorithm analysis

The aim behind controlling BP algorithm is to make plate of upper robotics system to do all exercise to be by the therapist in the same time with all constraint . The training of neural network, lots of keep scenes constructed in middle size match platform, data, totally 400 groups successful pass samples data recorded to BP neural network training; before training, normalization handling of samples data should be done, from which initial value of weight adopt random other learning parameters α = 0.5 = η, through nearly 1 hour learning, network tends to convergence state**,** the errors of network error is roughly equal to 0.001, its convergence process

RESULTS

Figure (6) shows the training error of a network with one hidden layer trained on a small data segment. The network has properly learned how to produce steering angles that match the targets (Figure 6-a). However, notice the paths in Figure (6-b) and (6-c). The blue paths show the simulated result of a robotics during using our neural network to produce desired velocity and angles of platform commands. After 1000 iterations, the network has learned a reasonable concept of obstacle avoidance for this situation. After 200 iterations, though, the network is over fitted to the target line.

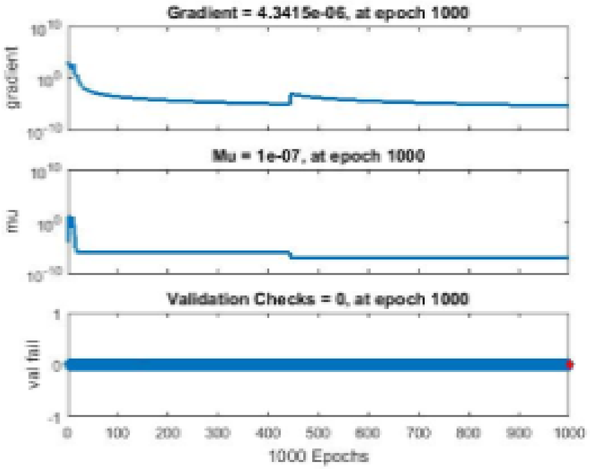

Figure (6-a)

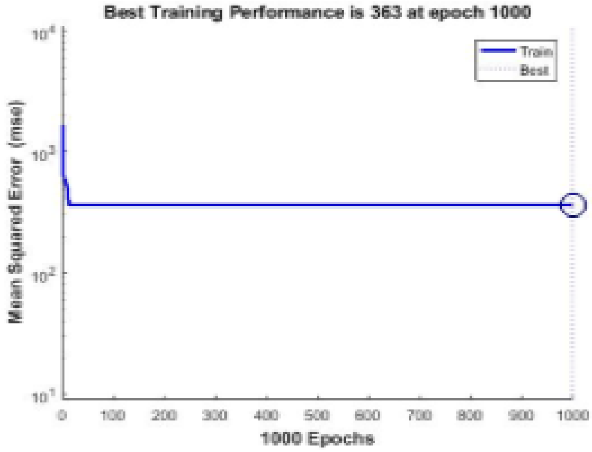

Figure (6-b)

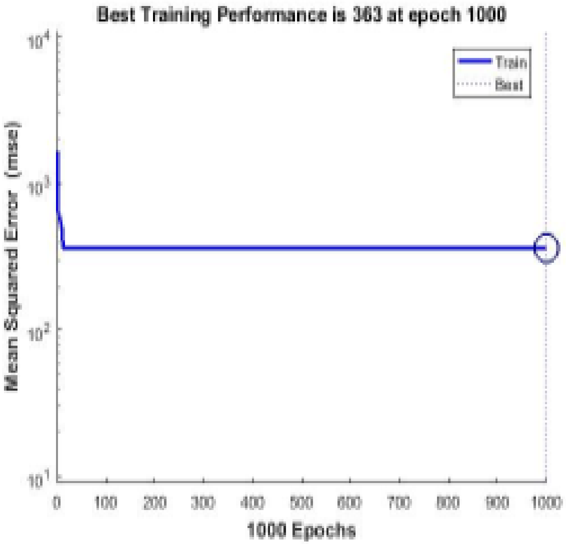

Figure (6-c)

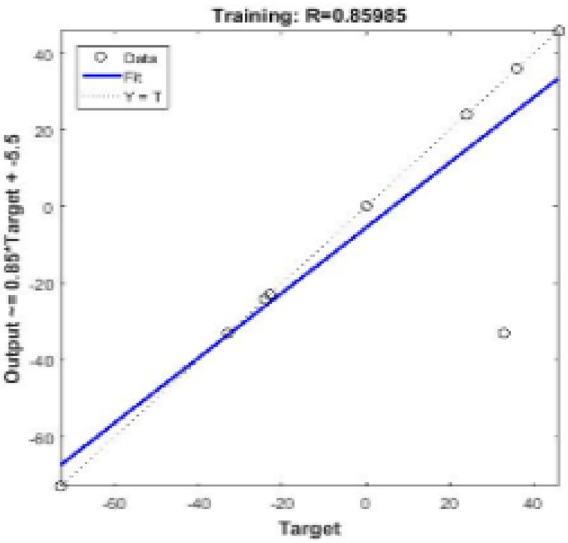

Figure (6-d)

Figure 6. Training results of Neural Network

CONCLUSION

In this study, a therapy training robot was presented and controlled for lower-limb rehabilitation. The robot manipulator was controlled through a (Arduino card). Manual and self-assistance training performed by the patient and also all other active and passive trainer can be supported by this devices with this interface. It was explained through experiments done hospital subjects that the RM can perform the necessary training as well as mimic manually exercises performed by the patience .

REFERENCES

[1] AL-Hussein, A. B. A. (2017). Neural Network-Based Adaptive Control of Robotic Manipulator Application to a Three Links Cylindrical Robot. Iraqi Journal for Electrical & Electronic Engineering.

[2] AKDOĞAN, E. (2016). Upper limb rehabilitation robot for physical therapy: design, control, and testing. Turkish Journal of Electrical Engineering & Computer Sciences, 24(3).

[3] Akdoğan, E., & Adli, M. A. (2011). The design and control of a therapeutic exercise robot for lower limb rehabilitation: Physiotherabot. Mechatronics, 21(3), 509-522.

[4] Jia, C. (2015). Mechanical impedance of ankle as a function of electromyography signals of lower leg muscles using artificial neural network (Doctoral dissertation, Michigan Technological University).

[5] Dzahir, M. A. M., & Yamamoto, S. I. (2014). Recent trends in lower-limb robotic rehabilitation orthosis: Control scheme and strategy for pneumatic muscle actuated gait trainers. Robotics, 3(2), 120-148.

[6] Chowdhury, R. H., Reaz, M. B., Ali, M. A. B. M., Bakar, A. A., Chellappan, K., & Chang, T. G. (2013). Surface electromyography signal processing and classification techniques. Sensors, 13(9), 12431-12466.

[7] Kazem, B. I., Morad, A. P. D. A., & Hasan, K. M. 3-DOF Parallel robotics System for Foot Drop therapy using Arduino.

[8] Tsai, L. W. (1999). Robot analysis: the mechanics of serial and parallel manipulators. John Wiley & Sons.

[9] Schilling, R. J. (1996). Fundamentals of robotics: analysis and control. Simon & Schuster Trade.

[10] J. Dul and G. E. Johnson, "A kinematic model of the human ankle," Journal of Biomedical Engineering, vol. 7, pp. 137-143, 1985.

[11] S. Siegler, J. Chen, and C. D. Schneck, "The three-dimensional kinematics and flexibility characteristics of the human ankle and subtalar joints- Part I: Kinematics," Journal of Biomechanical Engineering, vol. 110, pp. 364-373, 1988.

[12] C. S. Parenteau, D. C. Viano, and P. Y. Petit, "Biomechanical properties of human cadaveric ankle- subtalar joints in quasi-static loading," Journal of Biomechanical Engineering, vol. 120, pp. 105-111, 1998.

[13] E. Kearney, L. Weiss, and R. Morier, "System identification of human ankle dynamics: Intersubject variability and intrasubject reliability," Clinical Biomechanics, vol. 5, pp. 205-217, 1990.

[14] R. P. Kleipool and L. Blankevoort, "The relation between geometry and function of the ankle joint complex: A biomechanical review," Knee Surgery, Sports Traumatology, Arthroscopy, vol. 18, pp. 618-627.

[15] Bullen, D. (n.d.). Tools To Treat Foot Drop on ADVANCE for Physical Therapy & Rehab Medicine. ADVANCE for Physical Therapy & Rehab Medicine. Retrieved February 28, 2013, from http://physical-therapy.advanceweb.com/Features/Articles/Tools-To-Treat-Foot-Drop.aspx

[16] Richard Sandor, M.D., Camino Medical Group, Orthopedics Scott Brone, P.T., C.S.C.S., Physical Therapy, 2007

[17] KOK-MENG LEE AND DHARMAN K. SHAH " Dynamic Analysis of a Three-Degrees-of-Freedom In-Parallel Actuated Manipulator",IEEE Journal of robotics and automation,vol 4,No.3,june1988.

[18] Lung-Tsia"robot analysis:mechanics of the serial and parallel manipulator", 3rd edition,1999.

[19] ROBERT J.SCHILLINH " FUNDAMENTALS OF ROBOTICS ANALYSIS AND CONTROL"

[20] Vala ́sˇek, M., Bauma, V., Sˇika, Z., Belda, K., and P ́ısˇa, P. Design-by-optimization and control of redundantly actuated parallel kinematics sliding star. Multibody Syst. Dyn., 2005, 14(3/4), 251–267.

[21] G. Liu, J. Gao, H. Yue, X. Zhang and G. Lu, "Design and Kinematics Analysis of Parallel Robots for Ankle Rehabilitation," Proceedings of the IEEE/RSJ Int. Conf on Intelligent Robots and Systems, Beijing, pp. 253-258, October 9 – 15, 2006.

[22] Michael McRoberts,"Beginning Arduino", ISBN-13 (electronic): 978-1-4302-5017-3, second edition, 2013.

[23] Patrick Di Justo and Emily Gertz," Atmospheric Monitoring with Arduino", ISBN: 978-1-449-33814-5, First Edition,November 2012.

[24] Simon Monk, "30 Arduino Projects for the Evil Genius", ISBN: 978-0-07-174134-7, 2010.

[25] Online, [Cited: Sep 10, 2014.], available at: http://arduino.cc/en/Main/arduinoBoardMega2560

[26] Online, [Cited: Sep 10, 2014.], available at: www.hacktronics.co.in/blog/1-using-the-l298-motor-driver-to-control-the-robotics-vehicle.

[27] I. Boldea, Syed A. Nasar, "Linear Electric Actuators and Generators," Cambridge University press, pp. 33–60, 1997.

[28] Hamid D. Taghirad , "Parallel Robots: Mechanics and Control," First Edition, 2013.

[29] John J. Craig, "Introduction to Robotics, Mechanical and control," Third Edition, 2005.

[30] Bl.Theraja, Kl. Theraja, "text book of Electrical Technology," 26th Edition, 2003.