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Intelligent Control Method of a 6-DOF parallel robot Used for Rehabilitation Treatment in lower limbs

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Original scientific paper

The process of empowering muscles in order to make them to a normal and common value is an expensive and prolonged work, in common available methods. There are some commercial exercise machines used for this purpose called rehabilitation systems. However, due to their insufficient motion freedom and prospect of being expensive, these machines have limited usage. Hence, it is clearly necessary that Mechatronic technologies should be used in this area. In this paper, an algorithm and an improved rule are presented for controlling a rehabilitation system of lower limbs which is implemented on a 6-Degree Of Freedom (DOF) Stewart parallel robot. Impedance control and adaptive control are used for this purpose. Estimation and optimization of control parameters will be done by artificial neural networks and genetic algorithms, respectively (intelligent strategy). Safety is guaranteed since some of controller parameters can be adapted under the stability conditions given by using Routh stability theory. Thereafter, the results of simulations are presented by defining a physiotherapy standard mode on a desired trajectory. MATLAB/SIMULINK is used for simulations. Finally, a comparative discussion between this strategy and common methods is devised.

Key words: Impedance control, Genetic Algorithm, rehabilitation robotic, parallel robot

Inteligentno upravljanje paralelnim robotom sa šest stupnjeva slobode korištenim za rehabilitaciju donjih udova. Proces osposobljavanja mišića za normalne funkcije je skup i dugotrajan uz korištenje dostupnih metoda. Postoje komercijalni strojevi za tu svrhu koji se nazivaju sustavi za rehabilitaciju. Zbog njihove nedostatne slobode pokreta i visoke cijene takvi strojevi imaju ograničenu upotrebu. Stoga je jasno da je u području rehabilitiacije potrebno koristiti mehatroničke sustave. U ovom radu prikazan je algoritam i poboljšano pravilo za upravljanje rehabilitacijskog sustava za donje udove koji je implementiran na Stewart paralelnom robotu sa šest stupnjeva slobode. Pritom je korišteno upravljanje impedancijom i adaptivno upravljanje. Za estimaciju i optimiranje parametara upravljanja koriste se neuronske mreže i genetički algoritmi. Sigurnost je garantirana jer se neki parametri regulatora adaptiraju prema uvjetima stabilnosti koji su dobiveni korištenjem Ruthove teorije stabilnosti. Nakon toga, rezultati simulacija prikazani su definiranjem standardnog fizioterapijskog rada na željenoj trajektoriji. Za simulacije se koristi MATLAB/SIMULINK. Konačno, u radu je dana i usporedba predložene strategije s uobičajenim metodama.

Ključne riječi: upravljanje impedancijom, genetički algoritam, roboti za rehabilitaciju, paralelni robot

1 INTRODUCTION

Human's dynamic system is an extraordinary harmonic system from the beginning; set and targeted so that it is always considered by scientists who are interested in the mechanisms of human motions. The lack of communication and coordination among different human organs may cause dynamic problems, imbalance in body movement or indeed it may lead to a collapse on the movement symphony notes. On the other hand, the lesion of cerebral palsy, weakness and laxity of the muscles during aging, traffic accidents, and war injuries, are considered as the main sources of handicaps. In community health, non-drug treatments are in the frontline of treatment, all over the world. One of these treatments is rehabilitation. Rehabilitation means the restoration of abilities to maximize independence and to empower muscles to lead them reach to a normal and common value. This process is an expensive and prolonged work. There are some exercise machines for rehabilitation purposes. The commercial passive orthoses and prostheses like Continues Passive Motions (CPM) can mimic the behavior of a healthy limb in a satisfactory way, but they are used only for low-speed walking. For normal and fast walking speeds, the limbs provide additional energy for propulsion at the desired trajectory [1-2]. Nevertheless these machines are used only for ankle function and because of their low degree of freedom, their poor dynamic efficiency and prospect of being expensive, they are used limitedly. The most important machines that are used widely in many medical centers for therapy and rehabilitation purposes are LOKOMAT [3], stocktickerALEX [4] and LOPES [5]. These machines have high degrees of freedom but their high cost causes them to be used limitedly [6-12]. It is observed that usually the devices developed for rehabilitation purpose employing two control methods including hybrid control (position and force control) and impedance control. Intelligent techniques which are optimized based on therapy sessions, were only used in a few numbers projects, in which , they were implemented on scarce systems, namely 1-DOF and 2-DOF robots and CPM only [7-8]. Furthermore, the low-cost proposed system is usually used for rehabilitation of one leg or limb. It is worth mentioning that parallel robots, due to high stiffness, fast response and motion in non-planar surfaces, are being preferred recently over their serial counterparts. They are being widely used from precise manufacturing and medical applications to simple construction and shipment activities [13-14]. In this paper, an algorithm and an improved rule are presented for controlling a rehabilitation intelligent system of lower limbs and implemented on a 6-DOF Stewart parallel robot that can be situated beneath the patient's feet and is able to simulate the stand pattern on the human's feet.

It will be shown that factors such as Cost, intelligency, safety, are most important factors in suggested method in comparative with other works.

Stewart robot that will be used for this purpose has been developed by the mechanical research group at K. N. Toosi University of Technology (Fig .1). It is capable of providing necessary ROM (Range Of Motion) and other rehabilitative treatments for the lower limb joints. The developed robot has a parallel kinematic structure with six actuating links connecting the fixed platform. Each actuating link has a U-P-S (Universal-Prismatic-Spherical) structure with an actuated prismatic joint. These joints are moved by pneumatic actuators [27].

The main goal of the developed system in this study is to introduce a low-cost method which can satisfy the patient's safety by a flexible structure under the intelligent and optimized control. This system can be used for rehabilitation of two legs. Corresponding rehabilitation scheme is shown in Fig .2.

The rest of the paper is organized as following: In Section 2, explains the control strategy used in the developed system. The stability conditions and patient's safety are presented in Section 3. Optimization of controller parameters using Genetic Algorithm (GA) is presented in Sections 4. In the fifth section implementation and simulation of the proposed algorithm are provided. Finally, Sections 6,7 include the discussions and conclusions, respectively.

Fig. 1. The University of K. N. Toosi parallel robot for lower limb rehabilitation

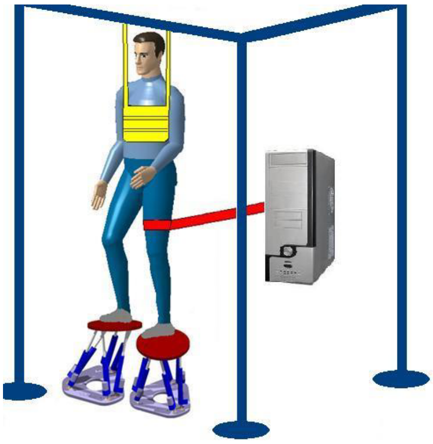

Fig. 2. Scheme of rehabilitation.

2 CONTROL STRATEGY USED IN THE DEVELOPED SYSTEM

Because of the interaction between human and robot, the conventional controllers such as PID, variable-structure, PD-gravity and etcetera cannot be only used. Control strategies of rehabilitation systems can be classified into three categories: force control, position control, position and force control [13-15]. Nevertheless, unlike industrial robots, rehabilitation-aided robots must be configured for a stable, safe and compliant motion while interacting with human [16]. The impedance control strategy proposed by [14-15] is one of the most appropriate approaches for such applications. Impedance control aims at controlling the position and force by adjusting the mechanical impedance of the manipulator to the external forces generated by contact with the manipulator's environment. Mechanical impedance is roughly an extended concept of the stiffness of a mechanism against a force applied to it [17]. Thus, the recommended control strategy for intelligent system control will be based on the combination of two strategies: impedance control and adaptive control (for adapting control parameters based on the patient's conditions, therapy sessions, etc.). The recommended control block diagram is shown in Fig .3.

Therefore, the necessary torques of robot joints are computed as: ((1) is obtained from the dynamic equation of the robot manipulator that is in contact with its environments in joint space [7].)

$$\begin{aligned}\tau =&h_N(q,\dot{q}) - M(q)J_y^{-1}(q)\dot{J}_y(q)\dot{q}\\ &- M(q)J_y^{-1}(q)M_d^{-1}(D_d\dot{y}_e + K_d y_e)\\ &+ \left[M(q)J_y^{-1}(q)M_d^{-1} - J_y^T\right]F\end{aligned} \tag{1}$$

Where q^{6*1} is the joint angle vector, $h_N(q,\dot{q})^{6*1}$ is the Coriolis and centrifugal force effects, $M(q)^{6*6}$ is the inertia matrix, $M_d(q)^{6*6}$ is the desired inertia coefficient matrix, $J^{6*6}$is the Jacobean matrix, D_d^{6*6} is the desired damping coefficient matrix, K_d^{6*6} is the desired stiffness coefficient matrix and F^{6*1} is the external force exerted on the manipulator (MP) by its environment (this force can be defined as action and reaction force between patient and MP). In Fig .3 q_d^{6*1} is the desired joint vector (prismatic joints in the Stewart robot), y^{6*1} is the end effector vector (trajectory vector), term $\frac{1}{RCs+1}$ denotes the transfer function of any link of the robot shown in Fig .1 where R, C are gas flow resistance and capacity of pressure suppler of any prismatic link of the Stewart robot, respectively [25]. Futhermore, $\frac{1}{s+T}$ is the transfer function of the approximated delay [25]. In the blocks of Fig .3, the subscript y denotes the task space.

In the proposed block diagram, Neural Network box is used to convert y_d (desired position) to q_d (desired length of the links in parallel robot). In this block diagram, it is assumed that:

$$y_e = dy = J(q)dq \cong J(q)q_e \tag{2}$$

Where y_e represents the error, or deflection of the manipulator (MP) from its reference position and q_e represents the error, or deflection of the joints from its desired position. The NN structure will be discussed in the following section.

2.1 Neural network and its usage in the proposed control strategy

An important area of application of neural networks is in the field of robotics. Usually, these networks are designed for learning and reconstructing complex non-linear mapping and have been widely used in the identification and control of a manipulator, which is the most important form of an assistant robot to track a trajectory, based on sensor data. Generally, kinematics of parallel robot are non-linear problems with more than one feasible solution which are difficult to obtain, thus a Multi Layer Perceptron (MLP) neural network is used to estimate the length of the links. The second idea of using neural networks is originated from the results of experiments, implying that there are training vulnerability centers in the adult mammalian spinal cord that can activate and control motor neurons which are responsible for walking patterns [18-20]. These walking patterns that have been previously reserved in the centers can be replaced by other neurons. Fig .4 shows the structure of employed neural network.

The input, output and target of NN in the suggested strategy are y_d, q_d and y, respectively as it is shown in Fig .3. This MLP neural network is used with two layers and tansig activation function in layer (1) and purelin activation function in layer (2). The best number of neurons in layer (1) is obtained from an iteration algorithm. The Levenberg-Marquardt optimization or trainlm algorithm is used for network training.

3 STABILITY CONDITIONS AND SAFETY

Patient's safety is one of the most important factors in rehabilitation systems and is satisfied by the stability of software and hardware. Stability conditions for robotic systems under impedance or stiffness controllers have been investigated in many researches [21]. In this paper, new asymptotic stability conditions for stiffness and impedance controllers based on the relationship between the prismatic joint variables of the robot (q) and their desired values (q_d) obtained from NN output, is presented. According to the (1) and the following substitutions:

$$F = Ky_e \tag{3}$$

$$\Omega = M(q)J_y^{-1}(q) \tag{4}$$

$$\begin{gathered}h_N(q,\dot{q}) = mgsin(q) \cong -10mq\\ \text{(For linearization and small movement)}\end{gathered} \tag{5}$$

Where g is the gravitational acceleration and m is the mass of patient, the transfer function of (1) will be:

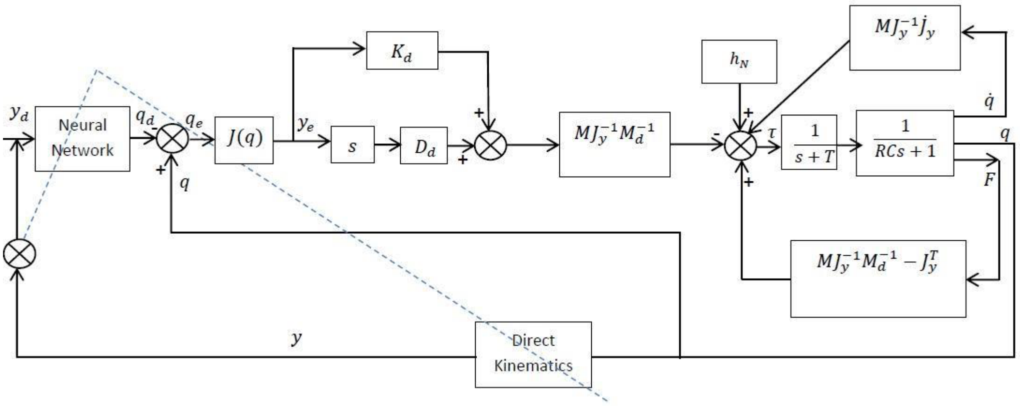

Fig. 3. The recommended impedance control block diagram used for robot control

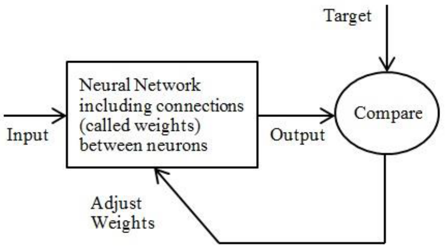

Fig. 4. The structural of neural network

$$G(s) = \frac{C(s)}{R(s)} = \frac{q}{q_d} = \frac{G_1}{G_2} \tag{6}$$

where

$$G_1 = (M_d^{-1}D_dJ)s + M_d^{-1}K_dJ - M_d^{-1}KJ + J^TKJ \tag{7}$$

$$\begin{aligned} G_2 = s^2(J + RC) + s(TRC + 1 + M_d^{-1}D_dJ) \\ + (M_d^{-1}K_dJ - M_d^{-1}KJ + J^TKJ + 10m) \end{aligned} \tag{8}$$

The denominator polynomial is:

$$d(s) = G_2 = a_0s^2 + a_1s + a_2 \tag{9}$$

After determining stability conditions of controller gains based on Routh theory [25], and taking into account that (M, K, D) are positive definite matrices, we will have:

$$RC > -J,\ M_d^{-1}K_dJ + J^TKJ + 10m > M_d^{-1}KJ \tag{10}$$

As a consequence, the control parameters (M_d, K_d, D_d) are very important factors in system stability and in this study they are finely tuned using a constrained nonlinear optimization strategy that will be discussed in the next sections. As it can be shown in the next sections, the deviation or deflection of actual path from desired one is also considered as another system stability criterion. In this paper, safety is guaranteed since some of the controller parameters can be adapted under the following criteria (adaptive control):

1. The stability constraints in (10).
2. Desired deviation or difference between actual and desired path P_d will be explained in the next section).
3. Different stroked patients (obtained from the physiotherapist).
4. Different states of progression in the therapy process (by progress of rehabilitation steps and improvement in movement or feeling less pain obtained from physiotherapist).
5. The action/reaction force (F) between patient and robot (by a force sensor).

The robot will be stopped when these safety factors are not satisfied.

4 OPTIMIZATION OF CONTROLLER PARAMETERS

The classical strategies of optimized control can be used to find the minimal deviation between actual and desired path. By getting transfer function, we try to find the optimal parameters (M_d, K_d, D_d), F These parameters are found to minimize the following cost functional:

$$\mathrm{Cost}_F = \int_0^n e\left(t\right)^2 dt \tag{11}$$

Where $e\left(t\right)$ is the deviation between actual and desired path and n is the number of stages in rehabilitation mode. Nevertheless, using these classical strategies resulted in more complexity of optimization problem and probably not finding a closed form answer owing to two reasons: firstly, the feedback loop in block diagram is not identical for different cases (robotics kinematic is different). Secondly, as far as the parameters are in matrix form, an increase in their number results in increasing the matrix dimensions and complexity of problem. Therefore, defining an alternative strategy without the transfer function in order to minimize the cost function can be useful in decreasing complexity. (12) is used for calculation of deviation between actual and desired path [17].

$$\Delta P = CF \tag{12}$$

Where C is the compliance matrix and it is defined as:

$$C = J^{*}K^{-1}J^{*T} \tag{13}$$

Where K is the stiffness matrix and J^{*} is defined as:

$$J^{*} = \left(F^{-1}\right)^{T}\tau^{T} \tag{14}$$

Now the impedance control parameters are modified so that this cost function can be minimized in (15):

$$\mathrm{Cost\_F} = \|\Delta P\| \tag{15}$$

In this case, because of the interaction between robot and human, the amplitude of force F is very important and its high value can damage the patient. Therefore, the cost function is rewritten as:

$$\begin{gathered}\mathrm{Cost\_F} = min(\|\Delta P\|)\mathrm{subjectto}\\ (\mathrm{F} \leq \mathrm{THRESHOLD}\,(\mathrm{Ft}))\end{gathered} \tag{16}$$

The threshold of force is changed based on the different stages of therapy and patient's improvement. We can incorporate constraint of F in cost function (16) and define a new cost function as:

$$\mathrm{Cost\_F} = \alpha F + \beta\left|\Delta P\right| \quad , \quad (\alpha + \beta = h, h \leq 1) \tag{17}$$

Where α,β, h are changed based on the different stages of therapy and patient's qualification (adaptive strategy). h is the accuracy factor and larger values of h will result in higher accuracy. Now, the control parameters such as (M_d, K_d, D_d) and even F used for determination of necessary torques of links based on (1), are selected using the genetic evolutionary algorithm which will be explained in the next section.

4.1 Genetic algorithm and its usage in the proposed control strategy

In the suggested genetic algorithm, value representation is used for chromosomes and the fitness function can be based on the (17). The main goal is to reach the minimum level of ΔP considering (F) which should not higher than the defined threshold. On the other side, since parameters are multi-dimensional, chromosomes will be multi-dimensional instead of being linear vector. In this case each chromosome can be shown as:

$\mathbf{M_d}$	$\mathbf{K_d}$	$\mathbf{D_d}$	**F**

The numbers of parameters in the Stewart robot (shown in Fig .1) that must be optimized, are $n1 * n1 * m1 = 6*6*4 = 144$. ($n1, m1$are the numbers of degrees of freedom and number of parameters ((M_d, K_d, D_d),F) respectively.) Thus, the chromosome length will be increased which would result in increasing the problem complexity. For this reason, it is essential to find some techniques to decrease the chromosome length. Some of the applicable techniques are:

1. Converting the population of chromosomes to multi population.
2. Fixing some of the parameters in any chromosomes which are not very important or critical.
3. Assuming the parameters of any chromosomes as diagonal matrix.

In the first technique, optimization of the whole parameters will not be done, simultaneity and probably it will not led to the optimum result. The second technique is incoherence with the desired aim (adapting the controller parameters under the stability condition for different patients and for different states of progression in the therapy process). Therefore, the third technique is applied in this study and the numbers of parameters that must be optimized are reduced to $n1 * m1 = 6 * 4 = 24$. It take to converge to final solution based on the mentored criteria discussed in section 3. The flowchart of suggested algorithm is shown in Fig.5.

5 IMPLEMENTATION AND SIMULATION OF THE PROPOSED CONTROL STRATEGY

The studied Stewart robot is shown in Fig.6.

The position vectors of the actuators length in terms of the last position can be expressed as a system of six equations described below [22]:

$$L_i^o = P_e^o + R_e^o b_i^o - a_i^o i = 1, 2, 3, \ldots 6 \tag{18}$$

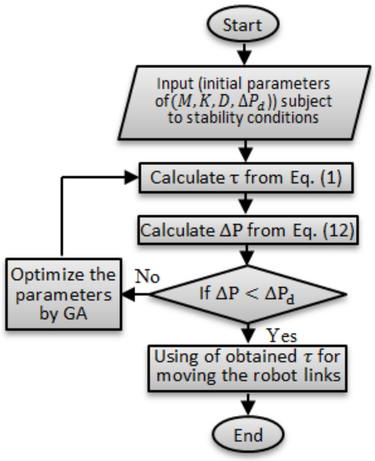

Fig. 5. Flowchart of the suggested algorithm

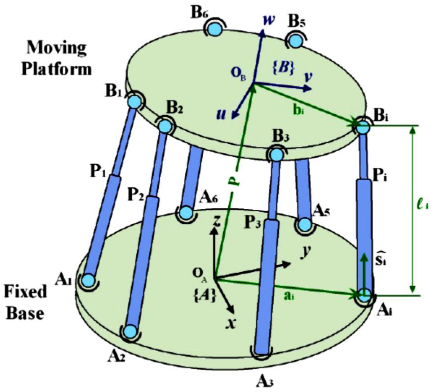

Fig. 6. The Stewart robot used for rehabilitation

Here P_e^o represents the position vector of point O_B with respect to O_A. b_i^o, a_i^o are the position vectors of the six connection points on the MP (manipulator or moving platform) and the actuator connection points at the FP (fixed platform) in Cartesian coordinates, respectively. R_e^o is the rotational transformation matrix of MP with respect to FP using a fixed axis rotation sequence of θ_x, θ_y and θ_z about X_0, Y_0 and Z_0 axes, respectively, or yaw, pitch and roll angles. R_e^o can be written as below [23]:

$$R_e^o = \begin{bmatrix} c\emptyset_z c\emptyset_y & c\emptyset_z s\emptyset_y s\emptyset_x - s\emptyset_z c\emptyset_x & \mathrm{s}\emptyset_\mathrm{z}\mathrm{s}\emptyset_\mathrm{x}+\mathrm{c}\emptyset_\mathrm{z}\mathrm{s}\emptyset_\mathrm{y}\mathrm{c}\emptyset_\mathrm{x} \\ \mathrm{s}\emptyset_\mathrm{z}\mathrm{c}\emptyset_\mathrm{y} & \mathrm{c}\emptyset_\mathrm{y}\mathrm{c}\emptyset_\mathrm{x}+\mathrm{s}\emptyset_\mathrm{z}\mathrm{s}\emptyset_\mathrm{y}\mathrm{s}\emptyset_\mathrm{x} & \mathrm{s}\emptyset_\mathrm{z}\mathrm{s}\emptyset_\mathrm{y}\mathrm{c}\emptyset_\mathrm{x}-\mathrm{c}\emptyset_\mathrm{z}\mathrm{s}\emptyset_\mathrm{x} \\ -\mathrm{s}\emptyset_\mathrm{y} & \mathrm{c}\emptyset_\mathrm{y}\mathrm{s}\emptyset_\mathrm{x} & \mathrm{c}\emptyset_\mathrm{y}\mathrm{c}\emptyset_\mathrm{x} \end{bmatrix} \tag{19}$$

The actuator displacements can be obtained by finding the Euclidean norm of the actuators length vector as:

$$L_i^2 = [P_e^o + R_e^o b_i^o - a_i^o]^T [P_e^o + R_e^o b_i^o - a_i^o] \tag{20}$$

Thus the Inverse Kinematic (IK) has a unique closed form solution. But because of complexity of the problem and non-linearity in dynamic models, in this study an MLP neural network is exploited for obtaining actuators displacements. The Jacobean matrix in (1) can be obtained as:

$$J = J_x J_q^{-1} \quad , \quad J_q = \mathrm{I}\,(6 \times 6 \text{ identitymatrix}) \tag{21}$$

$$J_x = \begin{bmatrix} s_1^\mathrm{T} & (b_1 \times s_1)^\mathrm{T} \\ s_2^\mathrm{T} & (b_2 \times s_2)^\mathrm{T} \\ \vdots & \vdots \\ s_6^\mathrm{T} & (b_6 \times s_6)^\mathrm{T} \end{bmatrix}_{6\times 6} \tag{22}$$

Where s_i, b_i denote the vectors $\overline{\mathrm{PB_i}}$ and $\overline{\mathrm{A_iB_i}}$, respectively [24].

For implementation of the suggested algorithm on the Stewart parallel robot, there are several parameters required to control in the MP as the following:

Desired position and orientation of MP and ΔP_d obtained from the physiotherapist (y_d).

Appropriate length of the robot links with desired trajectory are calculated based on IK from NN output (q_d).

The impedance control parameters are optimized by GA in order to determine the required torques (See previous section).

The desired position and orientation of the moving platform (MP) for ten different points (stages or times) are specified according to the Fig .7 that is given by following equations:

$$P_x = \sin(10x) \quad , \quad P_y = \cos(10y) \quad , \quad P_z = P_x P_y \tag{23}$$

where:

$$x = y = z = \frac{\pi}{60} \tag{24}$$

Now, the length of the links (q_d) are approximated based on desired trajectory (y_d) by MLP neural network. The real and approximated length of the link 1 (for concisely) is shown in Fig .8.

The weight and bias of proposed MLP neural network for link 1 approximation are obtained after training, as it is shown in Table 1. In this table w{1,1} and b{1} are the

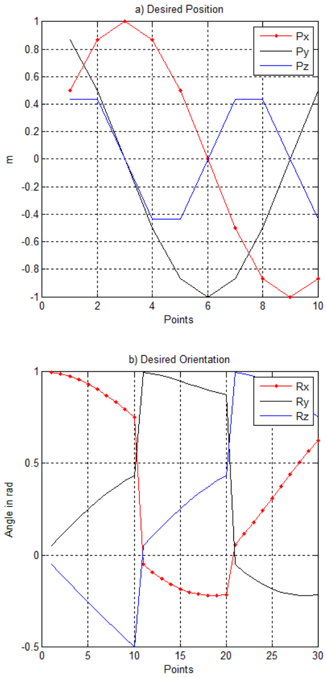

Fig. 7. a) Desired position b)Desired orientation of the moving platform for rehabilitation

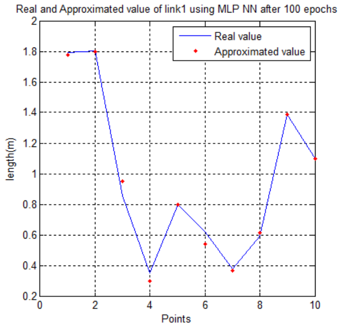

Fig. 8. The real (using IK equations) and approximated length of link1 (using MLP neural network) for ten various points according to Fig. 7.

Table 1. Weight and bias of proposed stockticke rMLP neural network for link 1 approximation.

w{1,1}	w{2,1}	b{1}	b{2}
-3.0256	1.0210	31.1198	-0.2190
-2.7424	0.1688	28.0413	
-3.0500	-0.5358	24.8967	
3.2121	-0.1381	-21.7632	
-3.3565	0.3967	18.6259	
2.9198	0.3254	-15.5926	

weights and biases of layer (1), respectively and w{2,1} and b{2} are the weights and biases of layer (2), respectively.

The MSEs between real and approximated length of six links after 100 epochs in MLP neural network are shown in Table 2 and the value of links length based on the desired trajectory (obtained by MLP NN) would be taken as Fig. 9.

Table 2. MSE of links length in Stewart robot approximated by an MLP neural network.

links	1	2	3	4	5	6
MSE	0.0016	0.0004	0.0018	0.0017	0.0015	0.0005

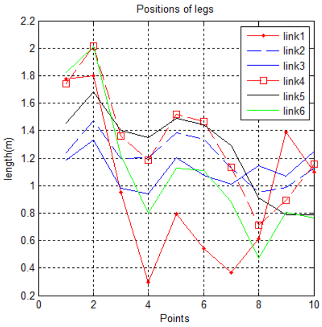

Fig. 9. Length of the all links based on the desired trajectory after solving the set of inverse kinematic equation by MLP neural network

The impedance control parameters are initially selected by trial and error subject to stability conditions. Then the optimized values are obtained by GA. These parameters are chosen as below:

$$K_d = \mathrm{diag}\left(Ks\right), D_d = \mathrm{diag}\left(Ds\right), M_d = \mathrm{diag}\left(Mds\right).$$

where the initial parameters are:

$$Ks = 0.05 \left(\frac{\mathrm{N}}{\mathrm{m}}\right), Ds = 0.05 \left(\frac{\mathrm{Ns}}{\mathrm{m}}\right)$$

,

$$Mds = 10(\mathrm{kg}).\mathrm{R} = 100\frac{\mathrm{lb_f/ft^2}}{\mathrm{lb/sec}}$$

,

$$C = 10\frac{\mathrm{lb}}{\mathrm{lb_f/ft^2}}, T = 0.1 \text{ sec.}$$

and $r_m = 0.3$ m, $r_f = 0.5$ m for radiuses of MP and FP in the Stewart robot, respectively. If we consider:

1. $\Delta P_d = 10$ cm.

2. $m = 100$ kg (Patient weight).
3. $d = 0.7\text{m}$ (Initial configuration of robot arms).

The forces of links are shown in Fig .10 and the required torques to move in the desired path are illustrated in Fig .11.

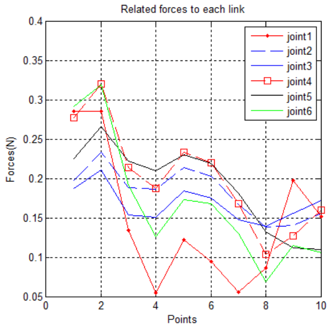

Fig. 10. Related forces to the any links in Stewart robot. These forces are the action/reaction forces between patient and robot

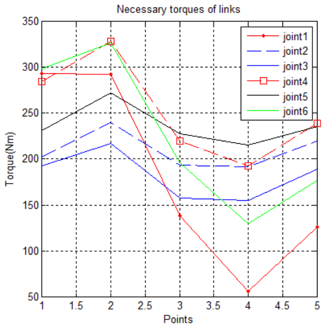

Fig. 11. The torques of the joints to move in the desired path. In some points the singularity may happen. Therefore, in this figure the number of points is considered 5.

The optimized control parameters based on related torques and forces are obtained as:

$Ks = 51.2\left(\frac{\text{N}}{\text{m}}\right)$, $Ds = 0.05\left(\frac{\text{Ns}}{\text{m}}\right)$, $Mds = 10.24(kg)$. Now, the obtained torques (from Fig.10) are used to move the Stewart robot links (actuators). Fig .12 shows the actual (q) (output of recommended control block diagram) and desired q_d link length (input of recommended control block diagram). Length of the link 6 is only shown.

Finally, the deviation between desired and actual path is shown in Fig .13.

According to the Fig .12 and Fig .13 the deviation or error between desired and actual variables is large at the beginning and this transient period leads to a bad pathological effect hence it is not suitable for rehabilitation without supervision. The deviation becomes smaller and converges to zero with the progress of simulation steps.

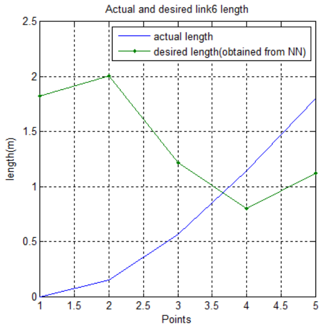

Fig. 12. The actual and desired length of the link 6. The desired links length are the references of control block diagram and estimated by MLP NN.

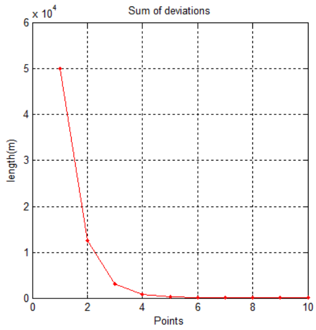

Fig. 13. The amount of deviation between desired (from physiotherapist) and actual path (from robot)

Finally, fitness function diagram of GA for (17) is displayed in Fig .14.

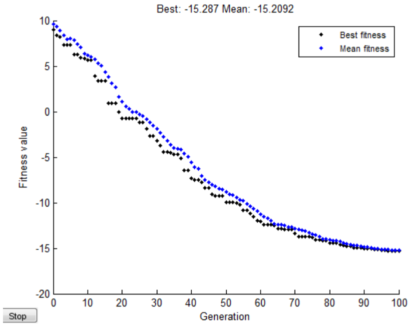

Fig. 14. Fitness function diagram of GA for optimization of control parameters.

And the optimal values for GA parameters are obtained as: α=1.1, β=2.006

6 DISCUSSION

In the case of assistive and rehabilitative devices, the marked variation of the character of disabilities from a patient to another strongly impedes the development of general control methodologies. Control schemes are customized to the pathology characteristics, the available biological signals, morphology of the remaining limbs, and the mechanical configuration of the device. In connection with this, the development of parametric and non-parametric adaptive schemes can offer new alternatives to solve problems that may be induced by the variation of the limb mechanical behavior. Generation of the source path is completely alternative and it is based on the patient's condition and the therapy's duration. In this research, the source path was specified after various efforts such as visiting the specialists of the physiotherapy and observing several sessions in that section to completely gather the whole required information. In comparison to the other related works, in it must be said that:

The proposed impedance control for CPMs in [7] and [8] can be only used for knee and hip on a planar surface, not for walking and gait pattern; then the patient must sit on a fixed place. In contrast, our study is used for walking and simulating gait patterns.

The work places needed for LOKOMAT [3] and LOPES [5] must be in a large room while the whole place that is needed for manufactured Stewart parallel robot is 2*2 m^2 in maximum.

The number of DOF in ALEX [4] is very high but in Stewart parallel robot it is limited to 6.

7 CONCLUSION

The aim of this research was to learn about the action of a physiotherapist toward each patient and to imitate this behavior in the absence of a physiotherapist that can be called "robotherapy". One of the most important advantages of this work is increasing the patient's safety. Safety is guaranteed since some of the controller parameters can be adapted under the stability condition for different stroked patients and for different states of progression in the therapy process. A different aspect of the defined chromosomes in the suggested algorithm in comparison to conventional methods is that they are defined as matrices not as vectors which were placed because of the abundance of DOF for the system. Another domineering characteristic of the suggested algorithm is simultaneous correction of the rehabilitation process at execution and progression time of rehabilitation. Control parameters and the cost function were optimized based on the patient's qualification and the duration of the remedy, which all can be variable.

To sum up, the proposed method can be considered as an intelligent strategy.

Only two parameters regarding the patient are used for starting the rehabilitation including the mass of patient and the ability in posture of ankle on the MP. The other parameters such as patient muscles, length and posture of whole body are not required.

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