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## Research

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## RESEARCH

# Intelligent and Hybrid Control Method of a 3-DOF Robot Used for Hip, Knee and Ankle Rehabilitation

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article

## Abstract

**Background:** There is an increasing trend in using robots for medical purposes. One specific area is rehabilitation. Rehabilitation is one of the non-drug treatments in community health which means the restoration of the abilities to maximize independence. It is a prolonged work and costly labor. On the other hand, by using the flexible and efficient robots in rehabilitation area, this process will be more useful for handicapped patients.

**Methods:** In this study, a rule-based intelligent control methodology is proposed to mimic the behavior of a healthy limb in a satisfactory way by a 3-DOF planar robot. Inverse kinematic of the planar robot will be solved by neural networks and control parameters will be optimized by genetic algorithm, as rehabilitation progress.

**Results:** The results of simulations are presented by defining a physiotherapy simple mode on desired trajectory. MATLAB/Simulink is used for simulations. The system is capable of learning the action of the physiotherapist for each patient and imitating this behaviour in the absence of a physiotherapist that can be called robototherapy.

**Conclusions:** In this study, a therapeutic exercise planar 2-DOF robot is designed and controlled for lower-limb rehabilitation. The robot manipulator is controlled by combination of hybrid and adaptive controls. Some safety factors and stability constraints are defined and obtained. The robot is stopped when the safety factors are not satisfied. Kinematics of robot is estimated by an MLP neural network and proper control parameters are achieved using GA optimization

**Keywords:** rehabilitation robotic, optimized control, intelligent control, impedance control, adaptive control, mechatronic, neural network, genetic algorithm.

## 1. Background

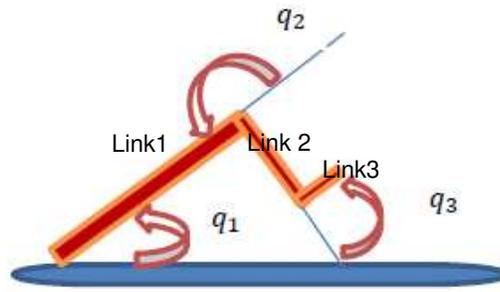
The process of strengthening muscles to their normal values is a costly labor which requires time and patience [7]. This process is named rehabilitation. An intelligent instrument that replaces the duty of the physiotherapist and can accomplish such routine physical movements without the guidance and assistance of a physiotherapist will simplify the process and lower the costs drastically [1]. There are many exercise machines for rehabilitation purposes like CPMs. Nevertheless, these machines are used only for ankle function and because of their low degree of freedom, their poor dynamic efficiency and prospect of high expense, they are used limitedly. The most important machines used widely in many medical centers for therapy and rehabilitation purposes are LOKOMAT [4], ALEX [5] and LOPES [6]. These machines have high degree of freedom but their high cost causes them to be used limitedly. Moreover, and their manipulation is hard and requires ingenuity. In addition, control system design is one of the major difficulties in construction of rehabilitation robots. Different approaches were developed to control movement of robot-aided therapy attached to human limbs [7-12]. It is observed that the devices developed for rehabilitation purpose usually employ two control methods including hybrid control (force and position control) and impedance control. Intelligent techniques, which are optimized based on therapy session, were used in few works. The main purpose of the developed system in this study is to introduce a low-cost system that satisfies

the patient safety by a flexible structure controlled by an intelligent control strategy. The hybrid and adaptive control are used for controlling the suggested system. As the reference input of the proposed control block diagram, neural networks is employed. Control parameters are optimized based on therapy sessions and safety factors and for this purpose a genetic evolutionary algorithm was applied. The suggested system can be used for rehabilitation of three limbs (knee, hip and ankle). The paper is organized as follows. Rehabilitation mode is explained in section 2. In section 3 control strategy used in the proposed algorithm is presented. Optimization of control parameters using GA is presented in section 4. In section 5 implementation and simulation of the proposed algorithm are performed. Finally, conclusions and discussions are presented in section 6.

## 2. Methods

### Rehabilitation mode

The proffered structure is based on the flexion and extension movement for knee, hip and ankle [7]. For this purpose a 3-DOF planar robot is defined that can be attached to the trunk of lower limb (Figure ure . 1).



**Figure ure I** A planar 3-DOF robot for proposed rehabilitation mode based on Flexion and extension movement.

In Figure ure . 1 link1 is aligned to the knee, link2 is aligned to the hip and link3 is aligned to the ankle.  $q_1$ ,  $q_2$  and  $q_3$  are the angles of hip, knee and ankle, respectively and the limits of them are based on the flexion-extension of knee, hip and ankle process shown in Figure ure . 1 and are written as:

$$0 \leq q_1 \leq \frac{\pi}{2} \quad (1)$$

$$\frac{7\pi}{6} \leq q_2 \leq 2\pi \quad (2)$$

$$0 \leq q_3 \leq \frac{\pi}{4} \quad (3)$$

As we know in robotic rehabilitation, the desired trajectory of manipulator obtained from the physiotherapist and then the related variables of the robot such as angles and velocity of them are computed based on inverse kinematic/dynamic problem. Thereafter these parameters are used for control of robot to track the desired trajectory. These issues will be described in the next stages.

## 3. CONTROL STRATEGY USED IN PROPOSED ALGORITHM

As mentioned earlier, as the reference input of proposed control block diagram, neural networks are employed. Thus, the neural network and its usages in proposed strategies are explained first and then the proffered control strategy will be described.

### 3.1 Neural network and its usages in proposed strategy

An important area of neural networks application is in the field of robotics. Usually, these



$h_N(q, \dot{q})^{2*1}$  is the Coriolis and centrifugal force effects,  $M(q)^{2*2}$  is the inertia matrix,  $M_d^{2*2}$  is the desired inertia matrix,  $J^{2*2}$  is the Jacobean matrix,  $D_d^{2*2}$  is the desired damping coefficient matrix,  $K_d^{2*2}$  is the desired e desired stiffness coefficient matrix and  $F^{2*1}$  is external force exerted on the end-effector by its environment (this force can be defined as action and reaction force between patient and end-effector).

The term  $\frac{R^2}{s(Cs+b)}$  denotes the transfer function of any arm of robot, equipped with a DC servo motor, where  $R$  is the gear reduction ratio in motor and the parameters  $C$  and  $b$  are the effective moment of inertia and viscous friction coefficient, respectively [21].  $\frac{1}{s+T}$  is the amount of approximated delay.

In the recommended block diagram, Neural Network box is used to convert  $y_d$  (desired position or input of NN) to  $q_d$  (desired joint angles or output of NN). And  $y$  is the target of NN. In this block diagram, it is assumed that:

$$y_e = dy = J(q)dq \cong J(q)q_e \quad (4)$$

Where  $y_e$  represents the error, or deflection of the MP from its reference position and  $q_e$  represents the error, or deflection of the joints from its desired position.

### 3.3 Patient safety in the proposed algorithm

Patient safety is one of the most important factors in rehabilitation systems and can be guaranteed by stability of software and hardware. Stability conditions for robotic systems under impedance or hybrid controllers had been investigated in some researches [7, 8, 14 and 15]. In this paper a new asymptotic stability conditions for stiffness and impedance controllers is presented using an appropriate Routh approach [21] based on the relationship between a joint angle of the robot and desired trajectory. Corresponding transfer function can be defined as:

[21] based on the relationship between a joint angle of the robot and desired trajectory. Corresponding transfer function can be defined as:

$$G(s) = \frac{C(s)}{R(s)} = \frac{q}{q_d} \quad (5)$$

According to the (3) and the following substitutions:

$$F = Ky_e \quad (6)$$

$$\Phi = M(q)J_y^{-1}(q) \quad (7)$$

$$h_N(q, \dot{q}) = mgsin(q) \cong -10mq \quad (8)$$

Where  $g$  is the gravitational acceleration and  $m$  is the mass of patient leg, the transfer function of (3) will be:

$$G(s) = \frac{C(s)}{R(s)} = \frac{q}{q_d} = \frac{(\Phi M_d^{-1} D_d J) s + \Phi M_d^{-1} K_d J - \Phi M_d^{-1} K J + J^T K J}{s^2(\Phi J + RC) + s(TRC + 1 + \Phi M_d^{-1} D_d J) + (\Phi M_d^{-1} K_d J - \Phi M_d^{-1} K J + J^T K J + 10m)} \quad (9)$$

The denominator polynomial is:

$$\begin{aligned} d(s) &= s^2(\Phi J + RC) + s(TRC + 1 + \Phi M_d^{-1} D_d J) + (\Phi M_d^{-1} K_d J - \Phi M_d^{-1} K J + J^T K J + 10m) \\ &= a_0 s^2 + a_1 s + a_2 \end{aligned} \quad (10)$$

After determining stability conditions of controller gains based on Routh theory [21], and taking into account that  $(M, K, D)$  are positive definite matrices, there will be:

$$RC > -\Phi J, \quad \Phi M_d^{-1} K_d J + J^T K J + 10m > \Phi M_d^{-1} K J \quad (11)$$

If we consider one of the joints of suggested robot (angle joint ) these substitutions will be obtained:

$$\begin{aligned} M &= I \quad , \quad J_y = J_y^T = L_g \quad , \quad J_y^{-1} = 1/L_g \\ h_n &= \tau_{gravity} = mgsin(q)L_g = mgqL_g \\ D_d, K_d &= I \quad , \quad M_d = \frac{1}{2}I \quad , \quad L_g = 1m, \quad g = -10 \text{ m/s}^2 \end{aligned}$$

Where  $m$  is the mass and  $L_g$  is the leg length of patient. Now the transfer function of (5) will be:

$$G(s) = \frac{-2sR^2 + kR^2 - 2R^2}{s^3(-C) + s^2(-TC - b) + s(-bT - 2R^2) + R^2(10m - 2 + k)} \quad (12)$$

The denominator polynomial is:

$$d(s) = s^3(-C) + s^2(-TC - b) + s(-bT - 2R^2) + R^2(10m - 2 + k)$$

Then the stability condition will be:

$$k > \frac{2TR^2 - 10mTR^2 - (TC + b)(2R^2 + bT)}{TR^2} \quad (13)$$

As it will be shown in the next sections, the deviation of actual path from the desired path is considered as another system stability factor. In this paper, safety is guaranteed since some of the controller parameters can be adapted under the following criteria:

- 1- The stability constraints in (11) or (13)
- 2- Deviation or difference between actual and desired path ( $\Delta P$  will be explained in next section).
- 3- Different stroked patients (obtained from physiotherapist).
- 4- Different states of progression in the therapy process (by progress of rehabilitation steps and improvement).
- 5- The action/reaction force ( $F$ ) between patient and robot (by a force sensor).

The robot is stopped when one of the mentored safety factors is not satisfied. Thus, the recommended control strategy will be based on combination of two strategies: impedance control and adaptive strategy. Controller parameters are finely tuned using a constrained non-linear optimization strategy such as GA that will be discussed in next sections.

#### 4. Optimization of control parameters

To find the minimal deviation between actual and desired path, the classic strategies of optimized control can be used and by getting transfer function, the optimal parameters  $((M_d, K_d, D_d), F)$  are found to minimize the following cost function:

$$Cost_F = \int_0^n e(t)^2 dt \quad (14)$$

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

complexity.

Eq. (15) is used for calculation of deviation between actual and desired path [17].

$$\Delta P = CF \quad (15)$$

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

$$C = J^*K^{-1}J^{*T} \quad (16)$$

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

$$J^* = (F^{-1})^T \tau^T \quad (17)$$

Now the impedance control parameters are modified so that cost function (18) can be minimized:

$$Cost_F = \|\Delta P\| \quad (18)$$

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:

$$Cost_F = \min(\|\Delta P\|) \text{ subject to } (F \leq THRESHOLD(Ft)) \quad (19)$$

The threshold of force is changed based on the therapy of different stages and patient qualification. We can incorporate constraint of  $F$  in cost function (19) and define anew cost function as:

$$Cost_F = \alpha F + \beta \|\Delta P\| \quad , \quad (\alpha + \beta = h, h \geq 1) \quad (20)$$

Where  $\alpha, \beta, h$  are changed based on the therapy of different stages and patient qualification (this means adaptive strategy).  $h$  can be called the accuracy factor as 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 (3) is optimized by using a genetic evolutionary algorithm that will be explained in the next section.

#### 4.1 Genetic algorithm and using it in proposed algorithm

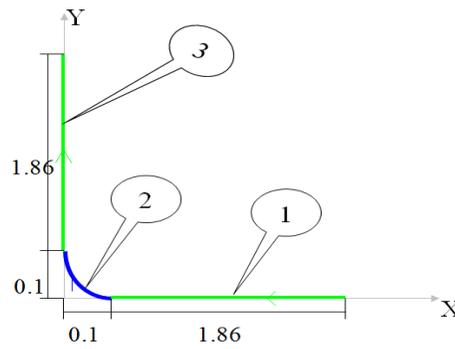
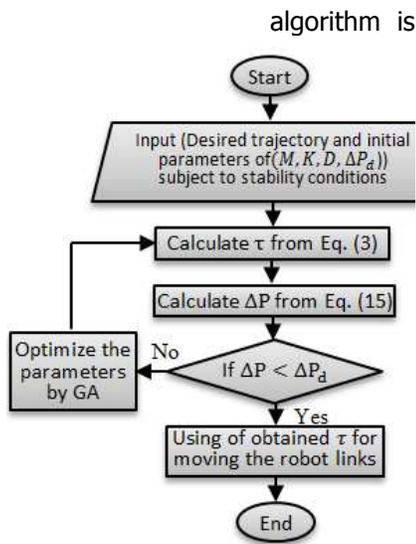
In the suggested algorithm value representation is used and the cost function is considered as (20). The main goal is to reach the minimum level of  $(\Delta P)$  considering  $(F)$  which will not be higher than the defined threshold. On the other hand, since the parameters are multi-dimensional, chromosomes will be multi-dimensional instead of being a linear vector. In this case each chromosome can be shown as:

$$\boxed{M_d \quad K_d \quad D_d \quad F}$$

Thus, the chromosome length will be increased which in turn would result in the increase of problem complexity. For this reason, it is essential to find some techniques to decrease the chromosome length. Some of applicable techniques are:

- Converting the population of chromosomes to multi population.
- Fixing some of the parameters in any chromosome that are not very important or critical.
- Assuming the parameters of any chromosome as diagonal matrix.

In the first technique, the optimization of the whole parameters will not be done simultaneously and probably it will not led to optimum result. The second technique is incoherence with the desired aim (adapting the controller parameters under the stability condition for different stroked patients and for different states of progression in the therapy process). Therefore, the third technique is applied in this study. The flowchart of suggested



shown in Figure 3.

Figure 3 Flowchart of suggested algorithm.

## 5. Implementation and simulations of the proposed algorithm

For implementation of the suggested algorithm on the planar 3-DOF robot described in Section 2, there are several requirements (in terms of position, joint torques, impedance parameters) needed to control the manipulator (MP) as the sequel:

- 1- Desired position and velocity (trajectory) of MP and  $\Delta P_d$  obtained from the physiotherapist.
- 2- Finding the appropriate joint variables with desired trajectory based on IK implemented by NN.
- 3- Optimizing of impedance control parameters using GA in order to determine the required torques.

All these requirements were explained in the previous sections.

For this purpose, a physiotherapy simple mode and its trajectory is defined which has been shown in Figure 4.

The angles and velocities of joints for this robot are planned in three phases:

- 1) Horizontal trajectory from  $(x, 0)$  to  $(x_r, 0)$  with the speed of 1m/s where  $x$  is the leg length in maximum extension and  $x_r$  is the distance between hip source and manipulator in minimum flexion in  $x$  direction (it is marked as 1'th phase in Figure 4).
- 2) Circular trajectory around hip from  $(x_r, 0)$  to  $(0, y_r)$  with the speed of 1 rad/s where  $y_r$  is the distance between source and manipulator in minimum flexion in  $y$  direction (it is marked as 2<sup>nd</sup> phase in Figure 4).
- 3) Vertical trajectory from  $(0, y_r)$  to  $(0, y)$  with speed of 1m/s where  $y$  is the leg length in maximum extension (in it is marked as 3<sup>rd</sup> phase in Figure 4).

**Figure 4** Trajectory in three phases.

- 4) The joint of ankle is rotated only according to condition of (3).  
Assuming:

$$x = 1.86 \quad , \quad y = 1.86 \quad , \quad x_r = y_r = 0.1$$

The velocities in three phases will be:

$$\begin{aligned} v_2 &= (-\cos(10.t - 18.6), \sin(10.t - 18.6)) \\ (21) \quad v_3 &= (0,1) \end{aligned}$$

Angles of the joints in this physiotherapy mode are obtained based on the equations of the inverse kinematic (IK) problem in the suggested 3-DOF planar robot.  
We assume:

$$\varphi = q_1 + q_2 + q_3 \quad (22)$$

The forward Kinematic in the suggested 3-DOF planar robot is:

$$x = a_1c_1 + a_2c_{12} + a_3c_{123} \quad (23)$$

$$y = a_1s_1 + a_2s_{12} + a_3s_{123} \quad (24)$$

If we consider these substitutions:

$$w_x = p_x - a_3c\varphi = a_1c_1 + a_2c_{12} \quad (25)$$

$$w_y = p_y - a_3s\varphi = a_1s_1 + a_2s_{12} \quad (26)$$

We will have:

$$w_x^2 + w_y^2 = a_1^2 + a_2^2 + 2a_1a_2c_2 \quad (27)$$

$$c_2 = \frac{w_x^2 + w_y^2 - a_1^2 - a_2^2}{2a_1a_2} \quad (28)$$

$$s_2 = \pm\sqrt{1 - c_2^2} \quad (29)$$

Thus, the value of  $q_2$  obtained by:

$$q_2 = \text{atan2}(s_2, c_2) \quad (30)$$

$$w_x = (a_1 + a_2c_2)c_1 - a_2s_1s_2 \quad (31)$$

$$w_y = (a_1 + a_2c_2)s_1 - a_2c_1s_2 \quad (32)$$

$$s_1 = \frac{(a_1 + a_2c_2)w_y - a_2s_2w_x}{w_x^2 + w_y^2} \quad (33)$$

$$c_1 = \frac{(a_1 + a_2c_2)w_x + a_2s_2w_y}{w_x^2 + w_y^2} \quad (34)$$

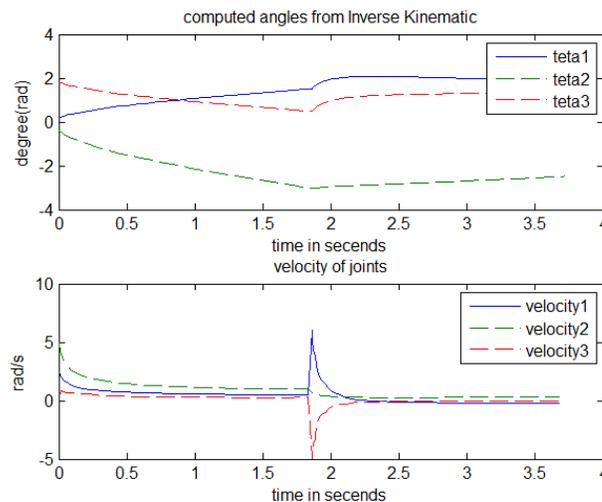
Thereafter,  $q_1$  will be:

$$q_1 = \text{atan2}(s_1, c_1) \tag{35}$$

And finally, from equation (22) we will have:

$$q_3 = \varphi - \theta_1 + \theta_2 \tag{36}$$

And they are shown in Figure 5. This Figure shows three phases in desired trajectory described in Figure 4.



**Figure 5** Angles and velocities of joints.

Where the range of joint1, joint2 and joint3 are complementary of  $q_1, q_2$  and  $q_3$  in (1),(2) and (3), respectively.

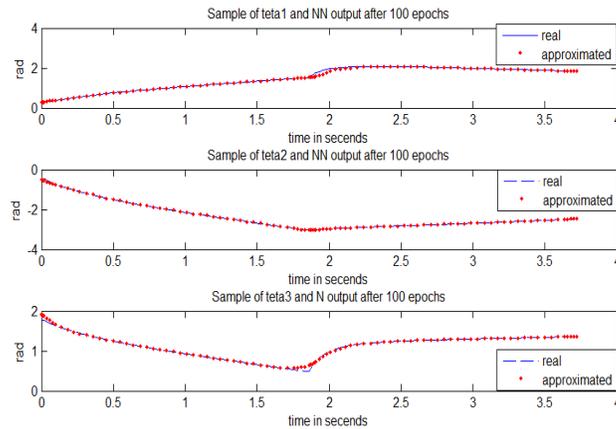
Now, the proposed MLP neural network is used for solving the IK problem. The weight and bias of the MLP neural network for joint1 approximation are obtained after training after 100 epochs and are shown in Table1. In this table  $w\{1,1\}$  and  $bi\{1\}$  are the weights and biases of layer (1), respectively and  $w\{2,1\}$  and  $bi\{2\}$  are the weights and bias of layer (2), respectively.

**Table1** Weight and bias of proposed MLP neural network for joint1 approximation.

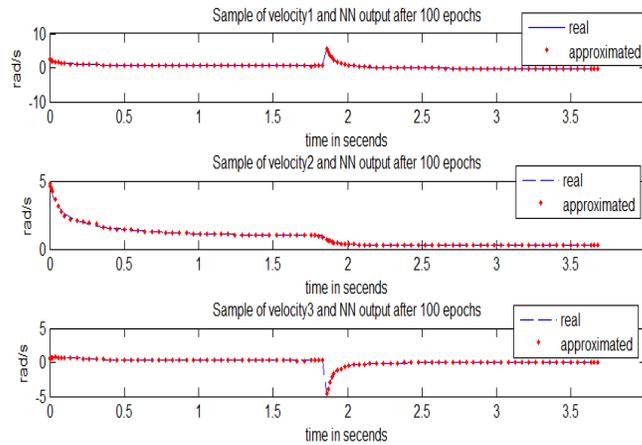
$w(1,1)$	$w(2,1)$	$bi(1)$	$bi(2)$
-1.3370	-2.7945	2.3883	0.4767
0.1686	-0.6542	-0.3739	
0.1437	-0.3735	-0.1026	
0.1332	-0.2878	-0.0565	
0.1914	-0.8640	-0.6795	
0.9674	2.5398	0.0812	
1.1624	-0.6009	-1.2252	
-0.1694	0.6654	0.3890	
-0.1473	0.4066	0.1242	
0.1583	-0.5220	-0.2194	
3.0389	-1.9478	-5.9277	
-0.0881	1.4560	-1.0628	
-0.1891	0.8422	0.6456	
0.1916	-0.8684	-0.6839	
0.1392	-0.3344	-0.0800	
0.1100	-0.1665	-0.0099	

<b>-0.1663</b>	0.6228	0.3329
<b>-1.0580</b>	0.0915	1.6298
<b>11.9988</b>	1.5388	-23.2530

The estimated values are shown in Figure 6 and Figure 7, respectively.



**Figure 6** Approximated joint angles that produced from MLP network after 100 epochs.



**Figure 7** Approximated joint velocities that obtained from MLP network after 100 epochs.

The impedance parameters  $K_d D_d M_d$  are initially selected by a trial and error method subject to stability conditions and then they are tuned using GA algorithm. These parameters are chosen as below:

$$K_d = \text{diag}(K_s), D_d = \text{diag}(D_s), M_d = \text{diag}(M_s).$$

where the initial parameters are:

$$K_s = 0.05 \left(\frac{N}{m}\right), M_s = 0.05 \text{kg}, D_s = 0.05 \left(\frac{Ns}{m}\right)$$

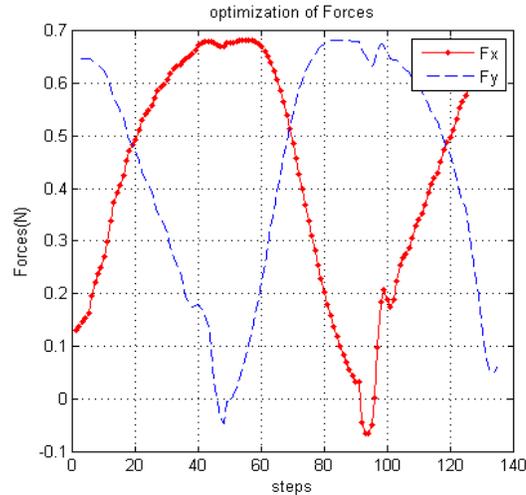
If we consider  $\Delta P_d = 10 \text{cm}$  and the characteristics of robot links as:

$$l(\text{robot arms}) = 1 \text{m},$$

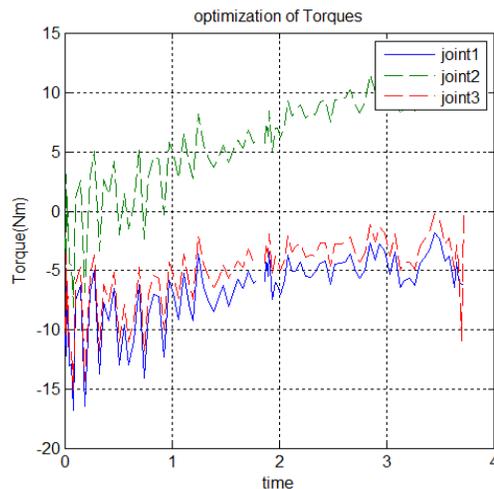
$$m_1 = 0.7 \text{kg}, m_2 = 0.5 \text{kg}, m_3 = 0.2 \text{kg} \text{ (link weight),}$$

$$T = 0.01 \text{sec}, R = 0.001, C = 0.1, b = 400.$$

The forces and torques that will be used for moving manipulator on the desired path (for 140 points of trajectory in 4 sec) are shown in Figure 8 and Figure 9, respectively.



**Figure 8** Forces on manipulator.



**Figure 9** Torques on the joints.

The evident peaks in Figure 9 denotes the complementary movement.

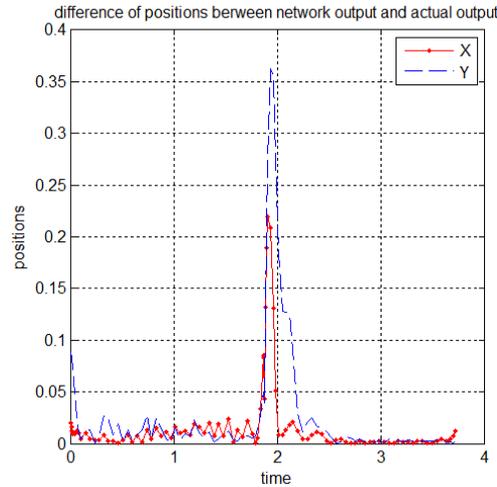
The final optimized control parameters based on related torques and forces obtained as:

$$M_s = 51.2 \left( \frac{N}{m} \right), M_{ds} = 4.8828 * 10^{-5} kg, D_s = 0.05 \left( \frac{Ns}{m} \right)$$

Now, the obtained torques from Figure 9 are used for moving the robot. It should be noted that the desired joint angles were approximated by MLP neural network that has been already described.

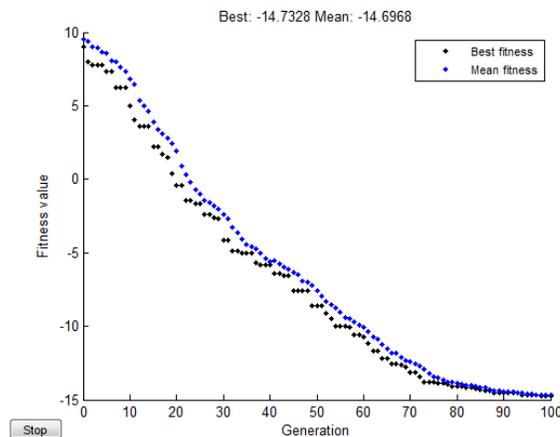
The difference between desired and actual trajectory is shown in Figure 10.

According to Figure 10 the deviation or difference between desired and actual variables is large for the first stages which are not suitable for rehabilitation without supervision. The deviation becomes smaller and converges to zero with the progress of simulation steps.



**Figure 10** Difference between desired and actual trajectory.

Finally, fitness function diagram of GA for Eq(20) is displayed in Figure 11.



**Figure 11** Fitness function diagram of GA

And the optimal values for GA parameters are obtained as:  
 $\alpha = 1.466$  ,  $\beta = 2.006$

## 6. CONCLUSION and DISCUSSION

In this study, a therapeutic exercise planar 3-DOF robot was designed and controlled for lower-limb rehabilitation. The robot manipulator was controlled by combination of hybrid and adaptive controls. Some safety factors and stability constraints were defined and obtained. The robot is stopped when the safety factors are not satisfied. Kinematics of robot is estimated by an MLP neural network and proper control parameters are achieved using GA optimization.

The advantages of the proposed algorithm can be classified as the following:

1. The system is capable of learning the action of the physiotherapist for each patient and to imitating this behavior in the absence of a physiotherapist that can be called robototherapy [20].
2. Generation of the source path is completely deliberative and it is done in accordance with 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.
3. The neural network identifiers were used for solving the inverse kinematic of robot. The first idea for using NN is to cope with a non-linear identification problem and the second, more important one, is that the patient's joints controlling system can be probably replaced by the artificial neural network.
  4. 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.
  5. To reduce the complexity of optimization of control parameters, genetic evolution method was used. 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 a system. In comparison to other related works, surplus mentioned issues, in particular it must be said that:
    6. The work places that are needed for LOKOMAT [4] and LOPES [6] must be in a large room while the whole place that is needed for manufactured Stewart parallel robot is 1 m<sup>2</sup> in maximum. Moreover, the cost of rehabilitation with LOKOMAT is very high.
    7. The number of DOF in ALEX [5] is very high but in Stewart parallel robot it is limited to 2.
    8. Only two parameters regarding the patient are used for starting the rehabilitation including mass of patient and ability in posture of ankle on the MP. The other parameters such as patient muscles, length and posture of whole body are not required.

### Abbreviations

CPM: Continues passive motions; GA: Genetic algorithm; MLP: Multi layer perceptron ;MP: Manipulator; F: F is determined via force sensors or force relations in dynamic model( $F = Mgsin(Q)$ ); IK: Inverse kinematic.

### Competing interests

The authors declare that they have no competing interests.

### Authors' contributions

WAA implemented the design on a manufactured 3-DOF robot. RF worked on the optimization.

### Authors' information

Wahab Amini Azar, received his B.Sc. in 1999 in Computer Engineering from the Shahid Beheshti University, Tehran, Iran and his M.Sc. in 2002 in Computer Engineering from the Amir Kabir University, Tehran, Iran. And currently he is Ph.D. student at Islamic Azad University, sciences and research branch, Tehran, Iran. At present he is an Assistant Professor at the Faculty of Electrical and Computer Engineering of Islamic Azad University Mahabad, Iran. Rasoul Farahi, received his B.Sc. in February 2013 Computer Software Engineering Technology from the Islamic Azad University Mahabad, Iran and M.Sc. in Software Computer Engineering at Islamic Azad University Of Mahabad in September 2018. Currently is Coach Department of Computer, Islamic Azad University, and University of Applied Science and Technology, Mahabad, Iran.

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University and currently some of handicapped patients are under therapy by this method. A 3-DOF robot manufactured by IAU robotic team for this purpose.

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# Figures

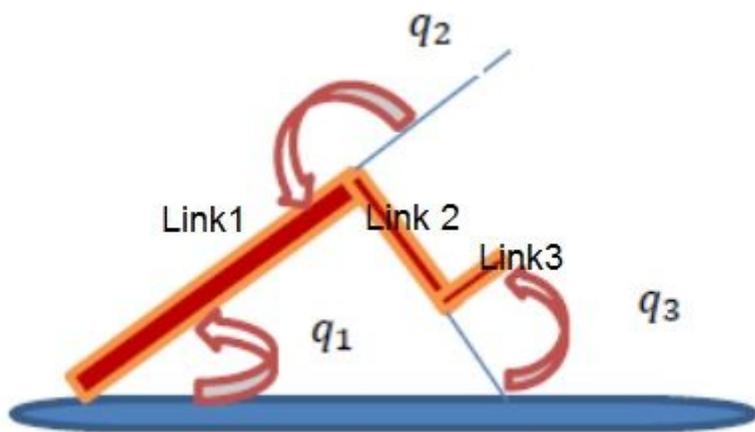


Figure 1

A planar 3-DOF robot for proposed rehabilitation mode based on Flexion and extension movement.

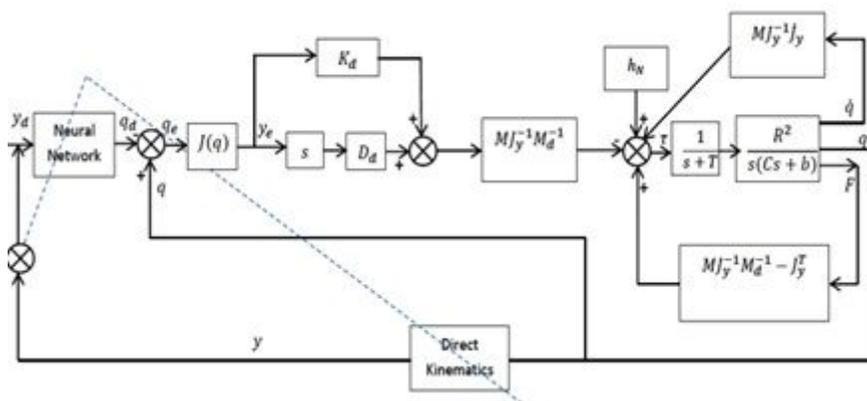


Figure 2

The impedance control block diagram

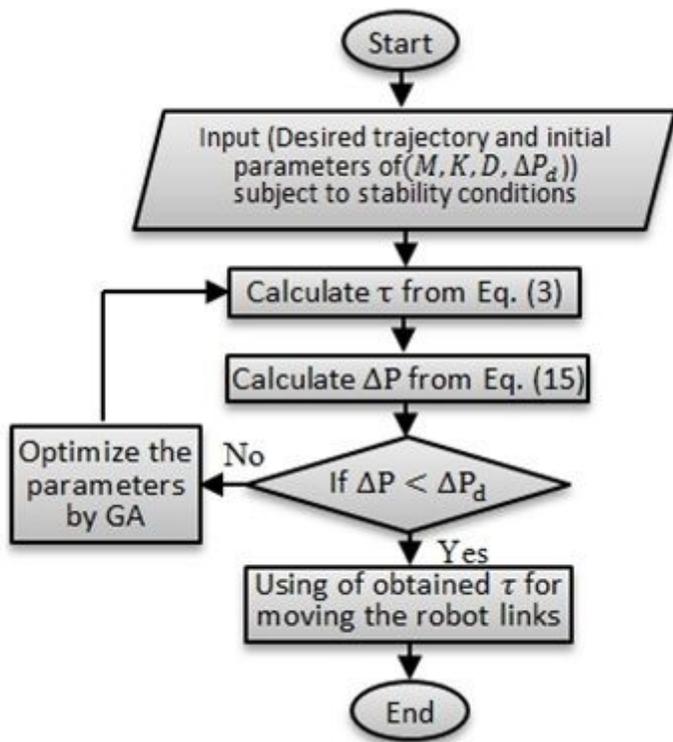


Figure 3

Flowchart of suggested algorithm

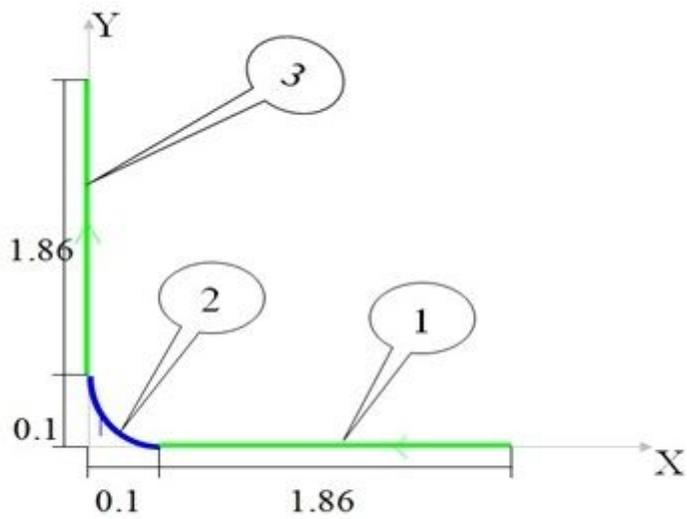


Figure 4

Trajectory in three phases

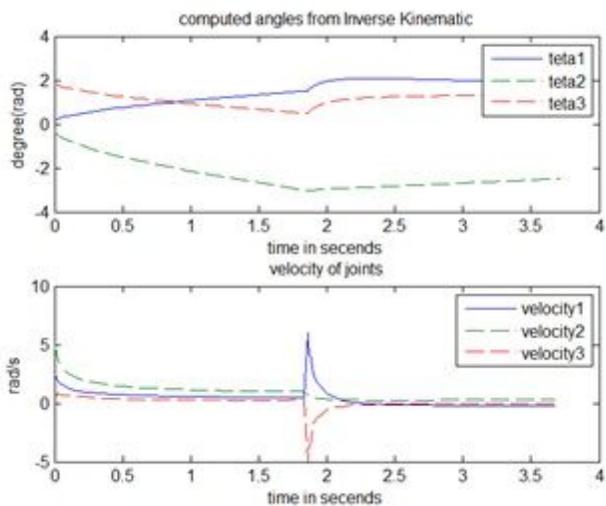


Figure 5

Angles and velocities of joints.

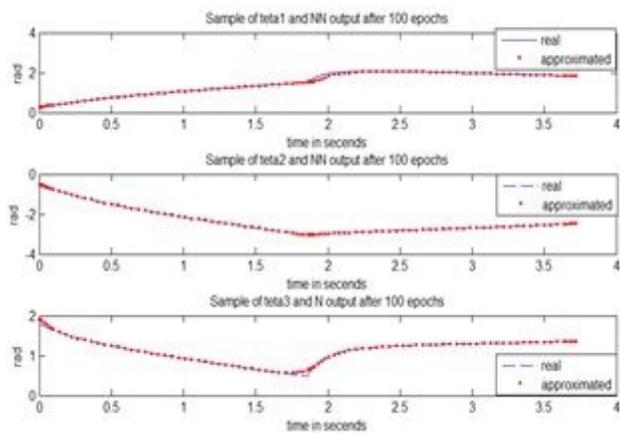
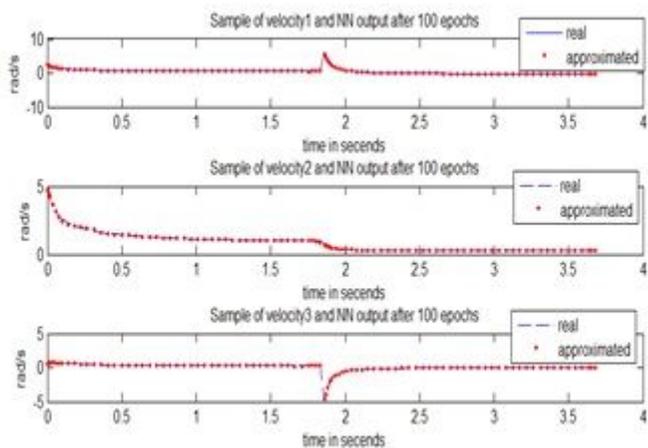


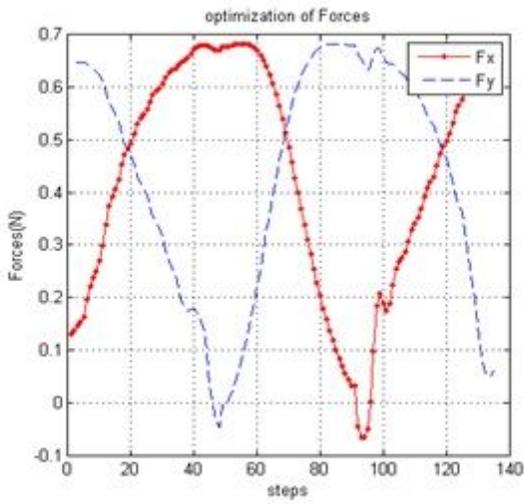
Figure 6

Approximated joint angles that produced from MLP network after 100 epochs.



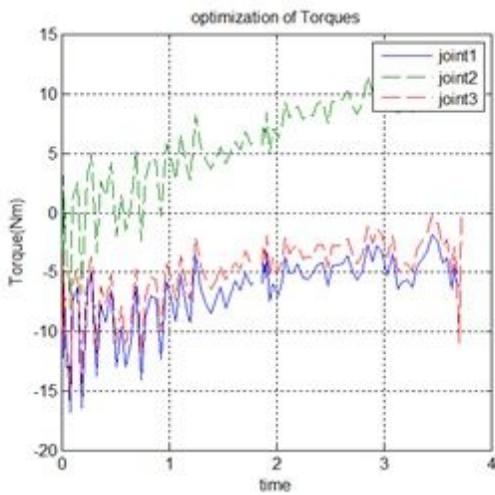
**Figure 7**

Approximated joint velocities that obtained from MLP network after 100 epochs.



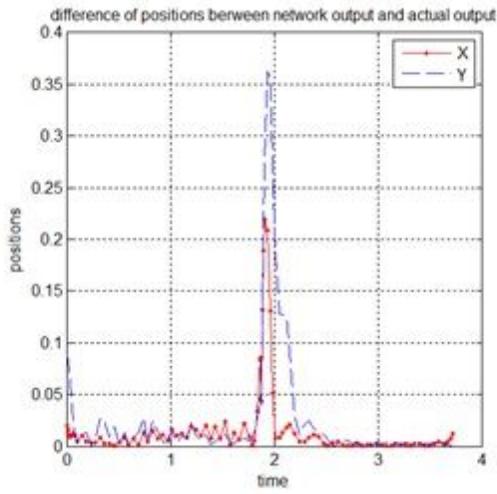
**Figure 8**

Forces on manipulator.



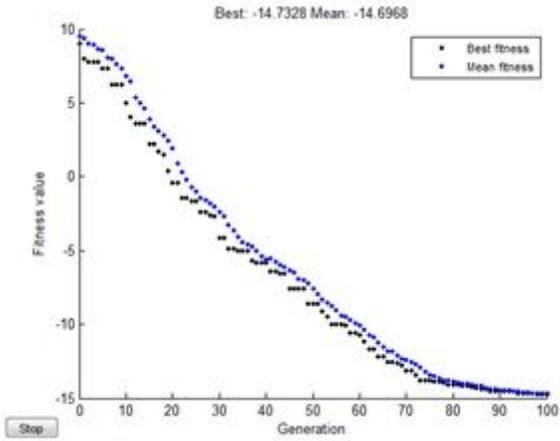
**Figure 9**

Torques on the joints.



**Figure 10**

Difference between desired and actual trajectory.



**Figure 11**

Fitness function diagram of GA