Cable Driven Robot for Lower Limb Rehabilitation

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Abstract— The purpose of this work is to develop a low-cost cable-driven manipulator robot to be used in the rehabilitation of human lower limb problems caused by stroke, accidents and cerebral palsy. The robot offers a lot of advantages but the main two is that is the robot is easily deployable anywhere where a power source is present, and that the therapist does not to be present with the patient in the same room to monitor the sessions. The robot consists of a stationary frame and an end-effector (splint) connected to four and up to eight wires and can conduct individual hip / knee motions. The paper starts with a look at rehabilitation of the lower limb, then moving on to the kinematics, workspace and hardware structure.

Keywords— Robotics, medical robots, rehabilitation, cable-driven parallel robots

I. INTRODUCTION

Ever since the exponential advancement in the field of robotics, many are using robots to infiltrate the field of medicine by using the advantages it could provide the field. In this paper we will focus on the advantages the cable robot could provide to the field of neural rehabilitation.

The paper is going to look into the rehabilitation of the motor skills for poststroke patients using the cable robots. The focus on poststroke patients stems from the number of people affected by it and the and the aftereffect. To begin with, Stroke is the leading cause of paralysis, about 33.7% of paralysis are cause as a result of a stroke [1]. globally 1 in 4 adults that live over the age of 25 will have a stroke in their lifetime according to the “World Stroke Organization” [2]. Regionally, the number of new strokes in Egypt per year may be around 150 000 to 210 000 if we generalize the local reports [3].

Cable robots are finding appeal in the fields of rehabilitation and haptic training. Fundamentally, this is due to their lightweight and large workspace as rigid links are replaced by lightweight cables. This allows them to aid therapists during training sessions by having the ability to perform intensive, different kind of motion strategies like passive, active an aid-assisted which can effectively improve the outcome of the therapy [4].

Rehabilitation of the patient and recovery of the motor functions all depends on the brain’s ability to reconfigure itself after injury[5] Stroke rehabilitation take different forms such as range of motion therapy, mobility training, constraint-induced movement therapy, electrical stimulation and robotic therapy [6].The success and effectiveness of the treatment depends on the severity of the damage in the brain and the timing of the rehabilitation. However, the success of the rehabilitation in most of the types of therapy depends on the activity of the supraspinal neural plasticity. The supraspinal neural plasticity, activates only if a neuronal signal that matches the proper afferents. To conclude, for an efficient rehabilitation the patient must intend and want to move in order to activate the cerebral cortex at the same time the muscle movement occurs [7]. Our robot traits the patient by the method called assisted motion, taking into consideration that assisting the motion of the patient and not creating the motion for the patient [8].

Early exoskeletons such as Lokomat allows the movement of patients’ limbs such as the knees and hips through the use actuators. Many of these exoskeletons use a myriad of sensors to be able to monitoring controlling and adjusting the movement of the device and the patient. An example of this is some use force sensor to allow the patient to have more freedom and control the start and end of their limb movement [9][10]. Another example of the sensor is using Cameras as visual feedback in order to visually process factors that include but are not limited to the location of the end effector and patient limb behaviour [11]. Newer versions of the exoskeletons like LOPES and ALEX attempt to induce the feeling of neutral limb movement by using elastic actuators [12][13].

Another type of devices, took advantages of that the cables robots provide over the use of exoskeletons,

devices like Hepatic Walker [14], G-EO [15] and lastly Gait Trainer I [16] including all its other variants that are used like the MoreGait both made under Stefan Hesse. All of these devices stimulate the limb by moving the end effector attached to it in a walking like movement.

TABLE I. SHOW MANY DIFFERENT TYPE OF PARALLEL ROBOTS USED IN REHABILITATION

Prototype	***Researcher, Affiliation, Country***	***Application***	***Classification***
MariBot	Rosati/Rossi, University of Padova, Italy	Redundantly constrained	Redundantly constrained
MACARM	Mayhew et al., IAI and RIC, USA	Upper limb neuro-rehabilitation	Redundantly constrained
Marionet-Rehab	Merlet, INRIA, France	Rehabilitation tasks and other industrial applications	Completely constrained
NeReBot	Rosati/Rossi, University of Padova, Italy	Neural rehabilitation	Fully-constrained
Sophia-3/4	Rosati et al., University of Padova, Italy	Post-stroke upper limb rehabilitation	Redundantly constrained
String-Man	Surdilovic et al., Fraunhofer IPK, Germany	Gait rehabilitation	Various
CAREX	Researcher, Affiliation, Country	Neural rehabilitation	Variable

The paper will go through the movement of our robot and the improvement it offers over traditional forms of therapy and even other robots. The hardware and the kinematics will be thoroughly discussed. From the kinematics the neural network will be discussed and the therapeutic motion will be achieved. Figure (1) show the major components of our project that the paper will touch on.

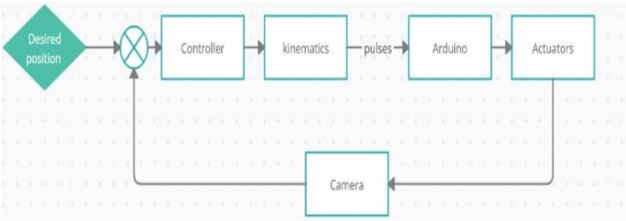


Figure 1: Shows the major components of our project.

II. Motion And Hardware

A. Motion Characteristics

First, The approach that the robot is taking in the motion is on of assessed motion. This means that the robot needs to learn the movements to assist the patients movement. Since the initial focus is on the patient's lower body (hips and knees), the motion done by the robot needs to be custom made to the patient's body proportions and specific treatment routine [17]. This is done by using various number of sensors like motor digital encoders that tracks the speed and positions of each motor as the therapist adjusts the motion pattern to fit the patient's treatment routine. [18] .As this iteration of the robot focuses on just the knees , the control just focuses on learning the pattern given by the therapist, maintaining the tension in the cables during all operations and flexion and extension on the knee. Figure (2) shows a simulation of our target setup.

Figure (2): Shows the simulation of our target movement.

B. Hardware

The Our work process contains several stages, and several layers present in the same stage. We are starting with a survey that will help us narrow down the design specification and allow us to have a clear image of the existing advancements already present in the field. The second stage is the design of both the mechanical and electrical working on parallel. After designing the model of the mobile platform and machine frame using SOLIDWORKS as shown in figure (1), we have calculated the kinematics and workspace calculations using MATLAB.

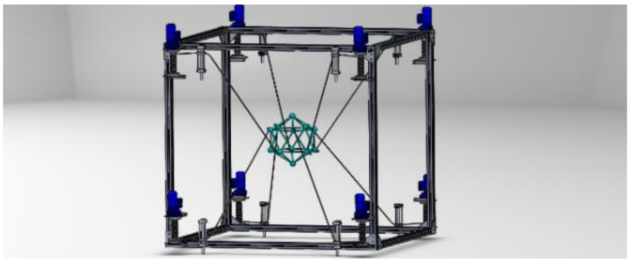
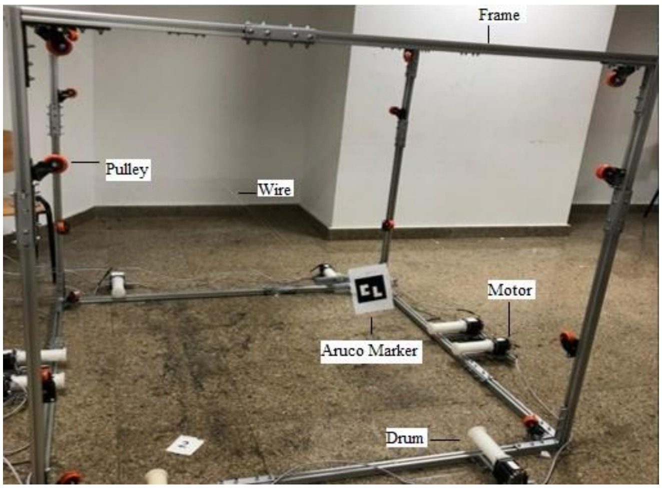
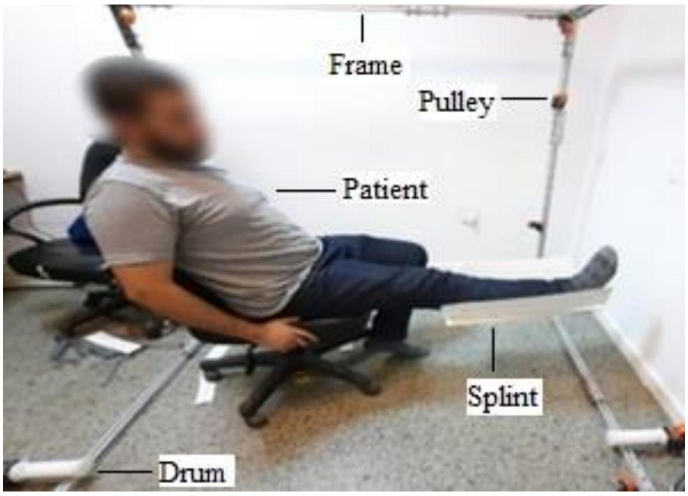


Figure 2: Shows the SOLIDWORKS model.

Our proposed device consists of four cables and could be up to eight cables arranged in a fixed frame and having a moving platform (splint) [19] , Figures (3) shows a prototype built at the Laboratory of Robotics at Nile university. Figures (4) and show a member from the team setting in the device in order to test it.



Figures 3 : Shows the robot moving to a target location (test without the patient).



Figures 4 : Shows the Robot Lifting the Limb of the patient.

Table A-1 shows the elements of the cable-driven parallel manipulator, consisting of : Nema 23 stepper motor with a drum connected to each motor's shaft, encoder with 500 pulses per revolution, Arduino, Kinect camera, driver for each motor and two guidance pulleys for each cable.

TABLE II. DEVICE PARAMETERS

Parameter	Value/component	units
Number of cables	From 4 to 8	
Size of robot frame	1.5 x 1.5 x 1.5	m
Rated Cable force	2-80	N
Actuator	Nema 23 stepper motor	-
Driver	HY-DIV268N-5A	-
Drum diameter	0.04	m
Cable material	Nylon	
Cable diameter	0.004	m
Cable strength	20	Kg
Controller	Arduino Mega & Raspberry Pi 4B	-

The acceleration and velocities are limited based on keeping the cables from reaching elastic properties and on keeping up with the limitations of the tracking system and this will be based on the frame rate of the tracking camera.

One of the most important hardware components is the drum length and diameter as it plays a role in the length of cables released per pulse [20]. Also, the diameter and material of the cables and diameter of the pully affect the workspace and the end position of the end effector. Below on the drum, cables and pully are shown in figure (5).

The drum dimensions are as follows, the cable diameter are 0.40 mm ,the umachined Artelon rod diameter are 4 cm and the mmaximum cable length to be released by the drum are 2.7 m .

The drum we used are machined and its dimensions are calculated based on the size of the cables and size of the drum.

All of the motors are connected to individual drivers, each driver is connected to the Arduino and the power supply. Each driver takes the pulse it needs to move in order to release or reel in the cable that is attached to it. The motor takes the pulses from the low-level control handled by the Arduino, the hardware setup for this is shown in figure (5) and figure (6).

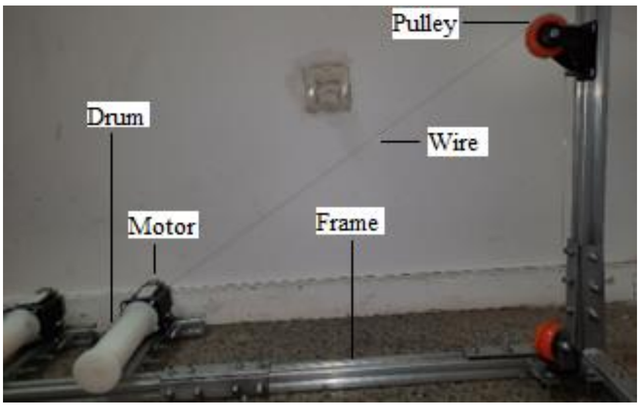


Figure 5: Shows the cables being reeled in by the motors from the guide pully ,around the drum

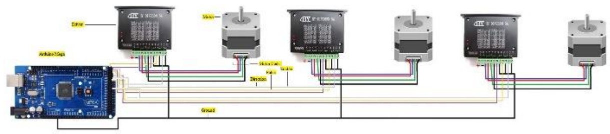


Figure 6: Shows the power supply, drivers, electric wiring, motors and the drums.

The Kinect I of the Xbox 360, where used as to measure the pose of the end effector, the translation and the orientation. The camera detects physical marker called fiducial markers

C. *Kinematics and Simulation*

When tackling the Kinematics of the cable driven robot, we have to note the differences between the standard model and the actual Physical cable robot. The difference raises from the assumptions made for the standard model, these factors not taken into consideration vastly affect the physical model behavior, these assumptions were put in place for the sake of simplification [21].

The kinematic model of cable-driven parallel robots is obtained similarly to the model obtained from traditional parallel structures [22]. The standard model is designed to know the general relation between the forces in different parts of the robot and how the motion of these parts is linked together. The standard model treats the cables as linear distance between to coordinates in space and both ends of the cables, the anchor point on the fixed frame "A_i" and the distal anchor point on the mobile platform "B_i", are modelled as spherical joints [23]. In addition, the following two vectors are assumed to be not dependent on the pose of the end-effector.

In this section we will used the standard model characteristics assumptions to drive the Chain closer equations of the robot [24]. The equation is derived in relation to the world origin frame "F_O" thus it is written as:

$$l_i = a_i^O - (r + R * b_i^E) \tag{2.0}$$

The equation is finding the length of the cable "l_i" in which " $i = 1,2, \dots, m$, where "i" is the number of cables and the transformation between frame "F_O" and "F_E" is in terms of prose $(r\ , R)$. Where "r" is the cartesian position of the end-effector (mobile platform) and "R" is the orientation of the end-effector.

Here the orientation matrix "R" of the end-effector can be written as:

$$R = R_Z(\theta_1) R_Y(\theta_2) R_X(\theta_3)$$

$$R = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta_2 & 0 & \sin\theta_2 \\ 0 & 1 & 0 \\ -\sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_3 & -\sin\theta_3 \\ 0 & \sin\theta_3 & \cos\theta_3 \end{bmatrix} \tag{2.0.1}$$

Equation (2.0.1) represents the matrices rotation transformation of the complete Euler angles transformation.

The length of the cable "l_i" can be written as a unit vector "u_i". Where "u_i" represents a vector pointing from the end-effector's distal anchor point "B_i" to the base "A_i". The direction is made so as the positive force on the cable is assumed to be the pulling forces. The normalized vector of the cable length "u_i" can be written as follows:

$$u_i = \frac{l_i}{||l_i||_2} \tag{2.1}$$

III. Future Work And Conclution

A. Future Work

In the future it is our to provide an accurate way to treat the hips of the patients, this will be done by designing around the setup shown in figure (7).

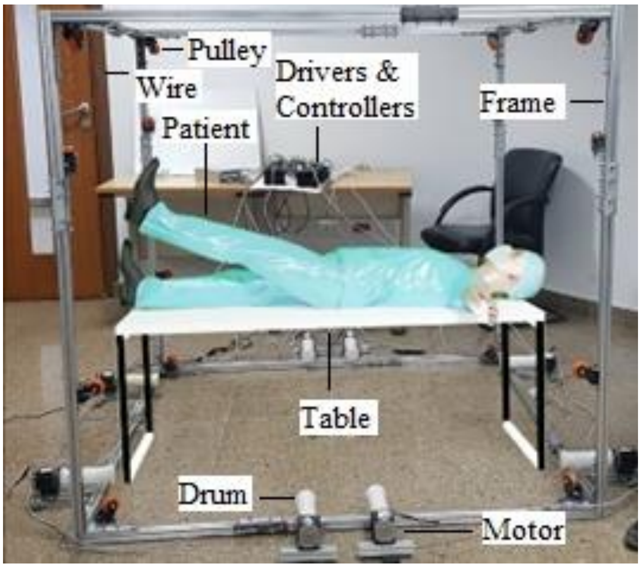


Figure 7: show the initial targeted position of the patients limb.

B. Conclution

In this paper, we presented an 8-cable parallel robot that is used in the rehabilitation of the lower limbs. A neural network was used in place of the forward kinematics that we used then to validate between the actual and theoretical motion needed for rehabilitation.

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