

Chest compression with 2-DOF parallel manipulator for cardiopulmonary resuscitation

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Abstract

Chest compression process is used for recovering patients who met with a cardiac arrest in emergency situations. Chest compression is the only possibility of rescuing patients during cardiopulmonary resuscitation (CPR). It is hard to achieve the exact chest compression's depth and rate even by experienced professionals as per the CPR guideline. A 2-DOF 2-RRR translational parallel manipulator was designed for delivering chest compressions. The kinematic analysis is carried out analytically. The workspace of the manipulator is examined in consideration of physical constraints imposed by joints. Finally, the manipulator operates with exact compression depth and rate during CPR.

Keywords: Parallel Manipulator, chest compression, Cardiopulmonary Resuscitation (CPR).

1. Introduction

The chest compression is an important technique during CPR, which is used in case of emergency situations for cardiac arrest patients. In CPR, the breathing and chest compression are the most essential situations, which are used at the site of an accident and in hospitals [1]. The chest compression is essential during CPR to create oxygen delivery and blood flow to the main organs of human body by directly compressing the heart [2].

Quality chest compression is a key element in the chain of survival and should be delivered at the rate of 100 per minute, a depth of 38-51mm according to the guidelines of resuscitation [3]. However, even for skilled doctors in emergency conditions, it is tough to perform chest compressions at the exact compression depth and rate. [4].

Manual chest compressions result in a cardiac output of about 20–30% of normal, and their efficacy is restricted by the rescuers endurance [5]. In addition, it requires few doctors to apply two hours to execute chest compressions to rescuing a patient in a hospital. Hence a medical robot utilized for chest compressions is needed [1].

In fact, parallel manipulators have many potential applications within the medical field, due to their effective performance under states of motion accuracy and high structural stiffness [1]. For instance, a 3-PUU translational parallel manipulator is designed and developed for CPR [6,7]. A 3-PRS parallel manipulator is designed for such applications [8]. A 3-RRPaR is modified version of DELTA parallel robot for CPR [9]. However, very few studies have been examined throughout the literature for the use of parallel manipulators to assist in CPR by utilizing a 3-DOF parallel manipulator.

2. Chest Compression

Recent medical studies have proved that the chest compression depth and/or force increases the blood flow during CPR [1]. For adults, chest compression force of 265-442N is directly applied to the chest as shown in Fig.1. The pressure is developed inside the chest due to this external force [10]. The necessary chest compression force should be applied to depress the chest between 38-51 mm according to CPR guidelines [11]. This is autonomous of body size, habitus and sex [12].

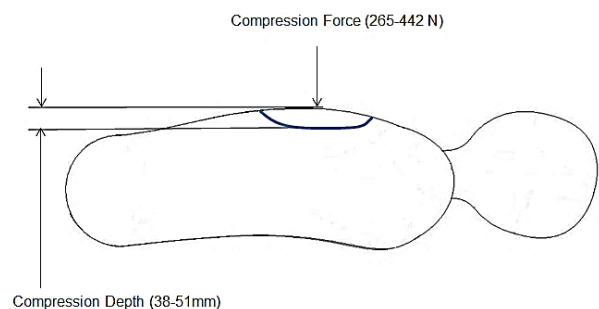


Fig. 1: Compression depth and/or force on patient

However, even for skilled doctors in emergency conditions it is difficult to apply chest compressions as per the required compression rate, depth and position [4]. Additionally, an augmented risk of breaking ribs and creating a flail chest, which then reduces the efficacy of CPR and risk of patients' lives [2].

Today, most devices for mechanical chest compression that are being used have limitations, because they are extremely large, are impossible to be precisely place on the patient's chest, can't be appropriately placed and controlled, are unstable on the chest and are expensive to install in public health centers [10,13]. Hence, the mechanical chest compression devices are not mostly used for

clinical applications even though the clear limitations with manual chest compression [1].

Parallel manipulator has potential to deliver the chest compressions like the manual chest compression. This device has been proposed to optimization of standard chest compressions during CPR. It is essential to develop a device for chest compressions that can permit free hands of the rescuer.

3. Device Description

The 2-RRR parallel manipulator is designed for chest compressions as shows in Fig.2. It consists of a fixed base, two upper links (driving links) and two lower links (driven links). In this model, all links are attached by a rotational joint. The upper links are controlled by individual motors. It is providing the end-effector with a translational motion with reference to fixed base. The manipulator motion is mainly in vertical translation for chest compression. The dimensions and mass properties for the mechanism are shown in Table1.

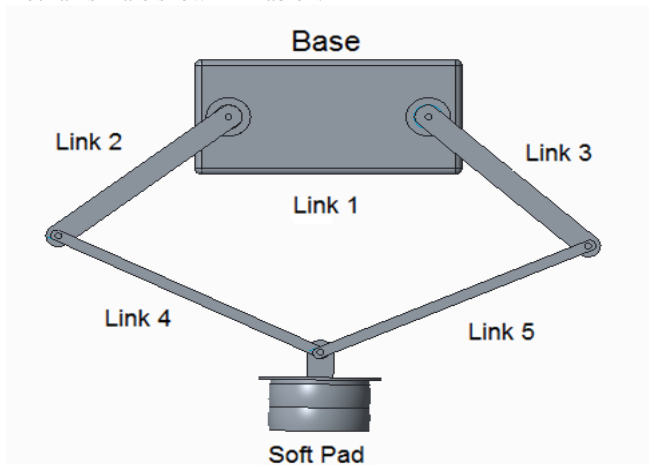


Fig. 2: 2-RRR Manipulator

Table 1: Dimensions and mass parameters

Link Number	Length(m)	Mass(kg)
1	0.2	1.5
2	0.4	2
3	0.4	2
4	0.5	0.9
5	0.5	0.9

4. Forward Kinematics

The forward kinematics identifies the link positions of the manipulator by actuated joint angles. The θ_A and θ_B are the relative angles to +Y-axis in counter-clockwise and clockwise direction as shown in Figure.3. It is assumed that the manipulator is symmetrical with reference to the origin; the upper and lower links are equal in length on both sides:

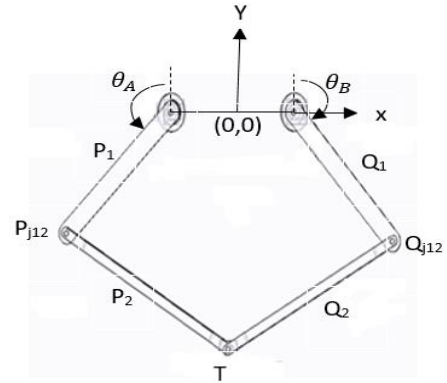


Fig. 3: Manipulator configuration

The following is the derivation of the end-effector (i.e. soft pad) coordinates given θ_A and θ_B . as shown in Fig. 4.

$$\|P_1\| = \|Q_1\|, \quad \|P_2\| = \|Q_2\| \tag{1}$$

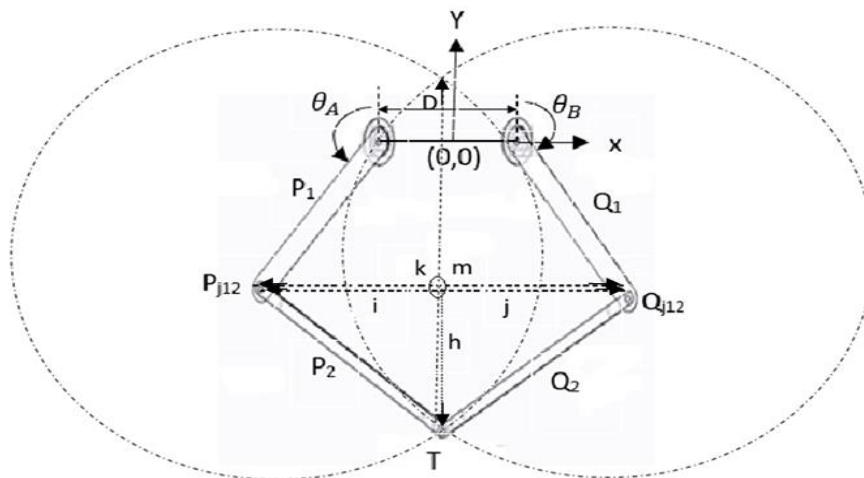


Fig. 4: Forward kinematics of the manipulator

The joint positions P_{j12} and Q_{j12} are simply determined by using Pythagoras:

$$P_{j12} \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} -\frac{L}{2} - P_1 \sin(\pi - \theta_A) \\ -P_1 \cos(\pi - \theta_A) \end{pmatrix} \quad (2)$$

$$Q_{j12} \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} -\frac{L}{2} - Q_1 \sin(\pi - \theta_B) \\ -Q_1 \cos(\pi - \theta_B) \end{pmatrix} \quad (3)$$

The end-effector (T) coordinates are obtained by the actuated upper links P_1 & Q_1 . It is calculated by the intersection of two circles traced by rotating the lower links, P_2 & Q_2 with reference to the joints P_{j12} & Q_{j12} . This is mathematically obtained as shown in below:

$$P_2^2 + i^2 = Q_2^2 + j^2 \quad (4)$$

$$\therefore i = \frac{P_2^2 - Q_2^2 + k^2}{2k} \quad (5)$$

$$h = \sqrt{P_2^2 - i^2} \quad (6)$$

$$m \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} P_{j12}(x) + \frac{i(Q_{j12}(x) - P_{j12}(x))}{k} \\ P_{j12}(y) + \frac{i(Q_{j12}(y) - P_{j12}(y))}{k} \end{pmatrix} \quad (7)$$

$$\therefore T \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} m(x) \pm \frac{h(Q_{j12}(y) - P_{j12}(y))}{k} \\ m(y) \mp \frac{i(Q_{j12}(x) - P_{j12}(x))}{k} \end{pmatrix} \quad (8)$$

In equation (8), the stated values of θ_A & θ_B are formed into two separate configurations of links for a closed loop structure. In practice, only one configuration is considered for chest compressions. i.e., the configuration of end-effector above the x-axis is considered as invalid for chest compressions.

5. Inverse Kinematics

The inverse kinematics of the manipulator is to obtain a set of joint angles from given coordinates of the end-effector.

$$\theta_A = -\frac{\pi}{2} + 2 \tan^{-1} \left(\frac{-e_A - \sqrt{e_A^2 - g_A^2 + f_A^2}}{g_A - f_A} \right) \quad (9)$$

$$\theta_B = -\frac{\pi}{2} - 2 \tan^{-1} \left(\frac{-e_B + \sqrt{e_B^2 - g_B^2 + f_B^2}}{g_B - f_B} \right) \quad (10)$$

Where

$$e_A = -2P_1T_y$$

$$e_B = -2Q_1T_y$$

$$f_A = -2\left(T_x + \frac{L}{2}\right)P_1$$

$$f_B = -2\left(T_x - \frac{L}{2}\right)Q_1$$

$$g_A = \left(T_x + \frac{L}{2}\right)^2 + T_y^2 + P_1^2 - P_2^2$$

$$g_B = \left(T_x - \frac{L}{2}\right)^2 + T_y^2 + Q_1^2 - Q_2^2$$

6. Workspace Analysis

Workspace of the manipulator is analyzed for improving mechanism in PTC creo and MATLAB software. In this analysis, the end-effector's coordinates are identified in MATLAB by joint angle constrains, i.e., $0^0 \leq \theta_A \leq 360^0$ and $0^0 \leq \theta_B \leq 360^0$.

The default constrains were considered from Table.1. The reachable workspace of the manipulator is obtained by given coordinates as shown in Fig.5

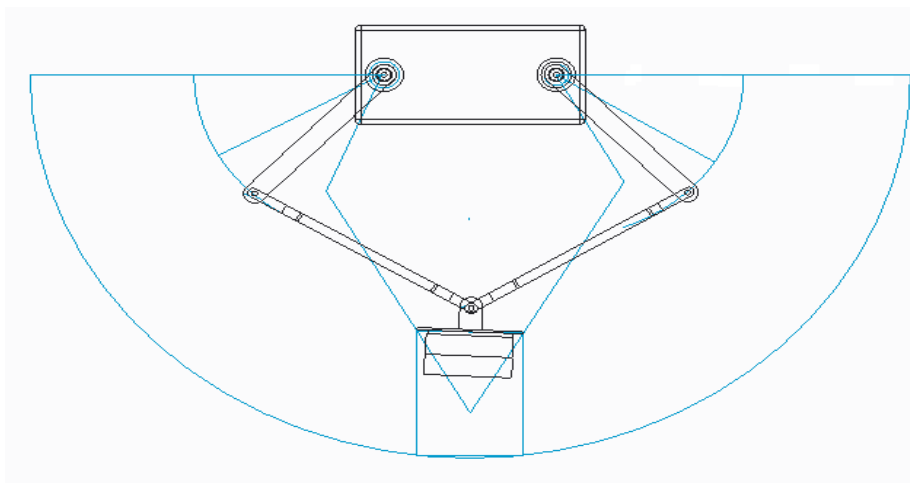


Fig. 5: Workspace of 2-DOF parallel manipulator

7. Structural Analysis

In this analysis, aluminum has been considered as structural material in ANSYS software. For adults, 30 to 50 Kg of pressure

to depress the sternum 40 to 50 mm. From the static analysis, it was found that the maximum stresses of the manipulator as shown in the Fig. 6, which is much less compared to the yield strength of the material.

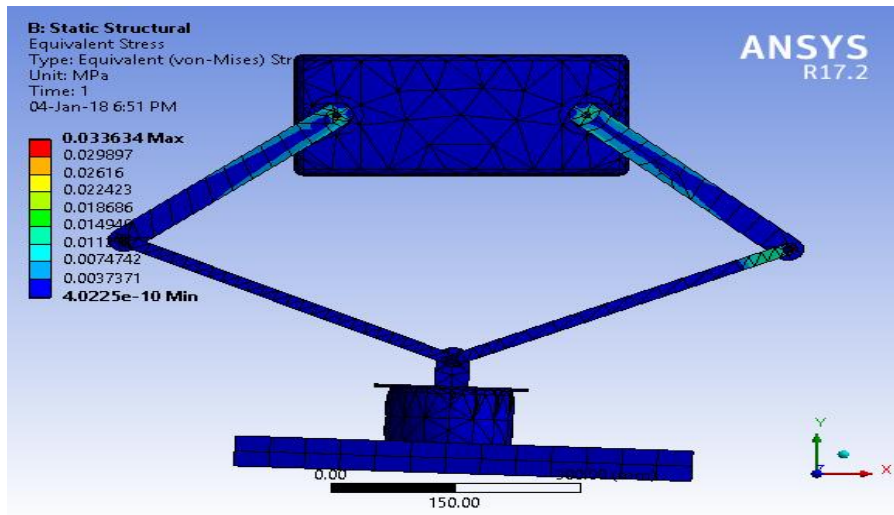


Fig. 6: von-mises stress of parallel manipulator

8. Biomechanical Analyses

The parallel manipulator has designed and simulated by using Biomechanics module of MSC ADAMS software in the real-time conditions. After bio-mechanical analysis, the displacement,

velocity and acceleration are obtained for the manipulator as shown in the Fig's. 7, 8 and 9. It is observed that, the manipulator attains 50 mm depth and 100 compressions per minute during chest compressions as shown in Fig. 7.

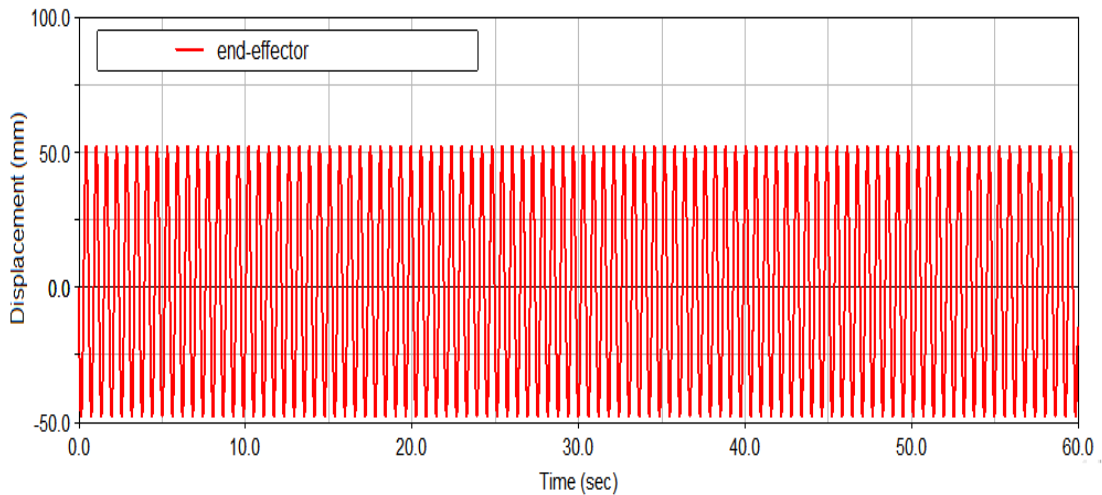


Fig. 7: Displacement of the Manipulator

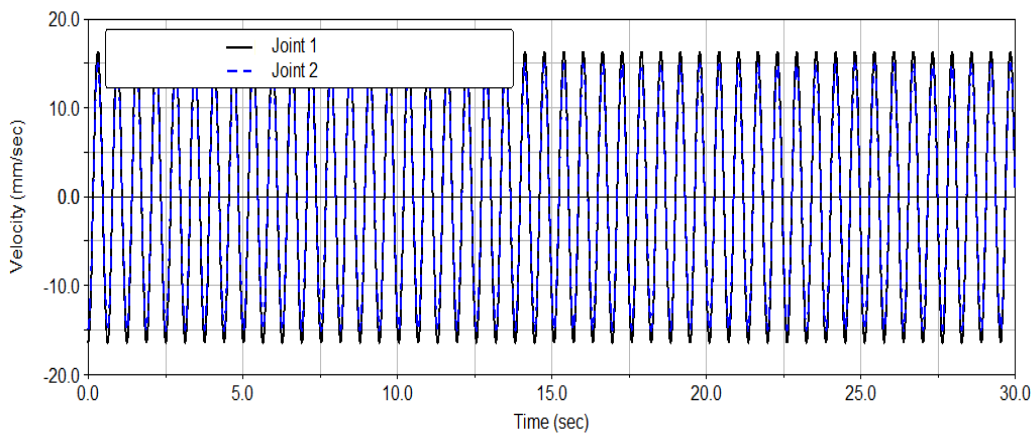


Fig. 8: Joint velocity

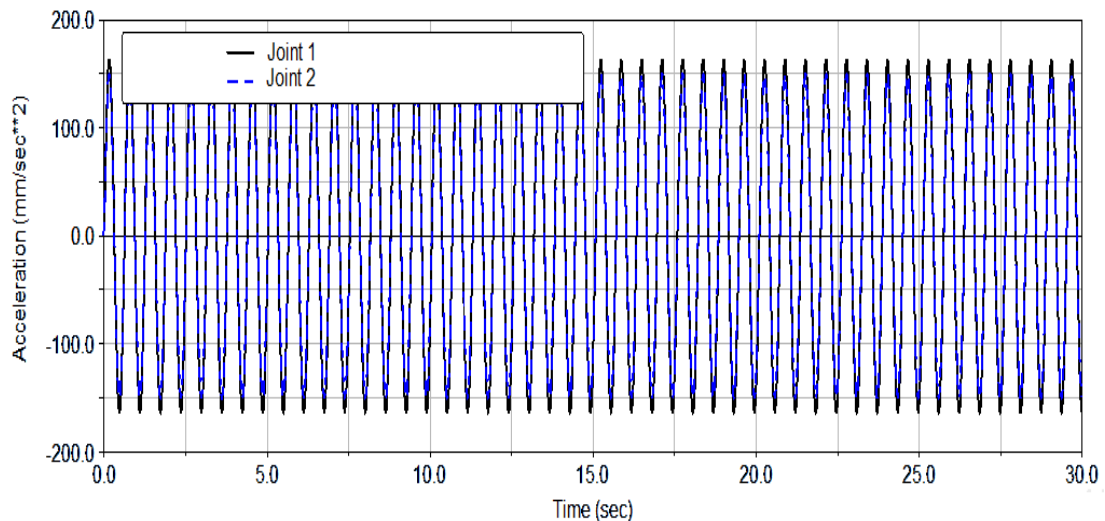


Fig. 9: Joint acceleration

9. Conclusions

In this work, a 2-DOF 2-RRR parallel manipulator is defined for chest compressions during CPR operation. From the static analysis, the parallel manipulator is capable of withstanding various loads that are inherent during mobility.

The biomechanical analysis and consequent simulation results shows that the 2-RRR manipulator can achieve 50 mm depth and 100 compressions per minute during chest compressions. These simulation results are significant because they correspond to the American Heart Association guidelines for performing CPR.

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