ABSTRACT

Uninterrupted chest compressions plays a key role in the survival of the cardiac arrest patient during cardiopulmonary resuscitation. For this purpose, a parallel manipulator operated by the pneumatic air pressure is designed, and the experiments were conducted on the Ambu feedback manikin by varying chest stiffness in the manikin for every bar of the pneumatic air pressure that is kept constant at different pressures ranging from 4 to 7.5 bar. From the experimental investigations, it is found that the obtained results were highly satisfied the standards of American Heart Association. It is observed that, American Heart Association guidelines were met, when the designed unit is operated under a pressure of 6 bar or more for the range of chest stiffness from 6 to 6.5 N/mm.

Keywords: Cardiopulmonary resuscitation; uninterrupted chest compressions; parallel manipulator; chest stiffness; Ambu feedback manikin. American Heart Association guidelines.
1. INTRODUCTION

The 2010 cardiopulmonary resuscitation (CPR) guidelines, emphasizes more on the importance of chest compressions, which have now become the first step in the CPR sequence (compressions, airway, breathing or circulation, airway, breathing (CAB), instead of airway, breathing, compressions, or airway, breathing, circulation (ABC)). However, achieving the effective chest compression is crucial in the CPR procedure. Compressions are applied over the lower part of the sternum to a depth of 50 to 60 mm. Compression rate of at least 100 per minute is required. The fatigue of the rescuer may also contribute significantly to the inadequate compressions. So, the mechanical devices are found to be efficient in performing chest compressions [1, 2]. The survival rate is affected not only by CPR but more importantly by its quality. Effective CPR can contribute more blood flow to the brain, heart and other organs, and thus increase the survival rate of patients with cardiac arrest. As per the revised AHA CPR guidelines, the chest compressions are given more importance and its effect on the blood pressure. However, during CPR even with the best manual chest compressions, cardiac output is approximately 20% to 30% of normal value, and performer's fatigue may also reduce the quality of the compressions. Besides, chest compressions will not be performed during the transportation of patients, which prolong the time between the arrest and CPR, and increase the difficulty of resuscitation. Therefore, to avoid or reduce these negative factors and to improve the CPR quality, mechanical devices are frequently used [3-5]. It is strenuous to perform chest compressions and therefore mechanical chest compressions have been looked upon with interest [6, 7].

Robotic applications, which are so diffuse in industrial processes, are gradually taking hold in the health field, where it is still seen as a pioneering technology. At the beginning of 2000, there were approximately 500 robots employed actively in the surgical field worldwide. This corresponds to a growth rate of 20%, which is analogous to that seen in the industrial area. Within 20 years, it is foreseen that there should be at least 15,000 robot devices in use in the health field [8]. In recent years, parallel robots have become an active research direction due to the merits in terms of high accuracy, high stiffness, and high load carrying capacity over their serial counter parts.

In this paper, a parallel manipulator which is operated by pneumatics as described in [9] is employed for performing the chest compressions on a feedback manikin. It shows that it is possible to perform uninterrupted, uniform compressions on manikin under different body stiffness. Parallel Manipulators have great potential applications in medical field due to their well performance in high structural stiffness, motion accuracy, and compact structures, etc., due to these merits, parallel mechanisms are employed to design a manipulator suitable for chest compressions in CPR. In fact, this is the main reason why the rescuer uses two hands instead of only one hand to perform the action of chest compressions. When performing chest compressions, the two arms of the rescuer construct a parallel mechanism indeed as described by [10-13].
2. MATERIALS AND METHODOLOGY

2.1. Description of parallel manipulator

The mechanism considered here is of parallel manipulator which is an end-effector. The parallel manipulator consists of three linear joints and two platforms namely fixed and movable. The fixed platform which is mounted on the horizontal arm is connected to three linear actuators parallel to each other by means of revolute joints and the other ends of the linear actuators or pneumatic cylinders of size φ16 X 75 mm stroke length are connected to movable platform called the sternum plate by means of spherical joints. Here the parallel manipulator is used for providing chest compressions during CPR [11-13]. The CAD assembly model of the manipulator along with its electronics control unit block diagram is shown in the Fig.1. Specifications of the designed parallel manipulator are given in Table 1.

![Figure 1 CAD assembly model of the manipulator with its block diagram of electronic controller.](image)

Table 1 Specifications of the manipulator.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Name of the component</th>
<th>Size in mm</th>
<th>Qty.</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vertical Column</td>
<td>Φ50 x 650</td>
<td>1</td>
<td>Mild Steel</td>
</tr>
<tr>
<td>2</td>
<td>Horizontal Bar</td>
<td>600 x 150 x 100</td>
<td>1</td>
<td>Mild Steel</td>
</tr>
<tr>
<td>3</td>
<td>Ball Screw</td>
<td>Φ30 x 350</td>
<td>2</td>
<td>Mild Steel</td>
</tr>
<tr>
<td>4</td>
<td>Fixed Platform</td>
<td>Φ142 x 6</td>
<td>1</td>
<td>Mild Steel</td>
</tr>
<tr>
<td>5</td>
<td>Sternum Plate</td>
<td>Φ54 x 6</td>
<td>1</td>
<td>Mild Steel</td>
</tr>
<tr>
<td>6</td>
<td>Linear actuator</td>
<td>Φ16 x 75</td>
<td>3</td>
<td>Aluminum</td>
</tr>
</tbody>
</table>

The mobility of parallel manipulator is determined by the following formula given by Grubler-Kutzback criterion, show in Eq. (1) [14]:

\[ F = \lambda (n - j - 1) + \sum_{i=1}^{j} f_i \]

Where \( \lambda \) represents order of task space, \( n \) represents no of links, \( j \) represents number of joints, \( f_i \) denotes degrees of freedom for each joint with \( i^{th} \) dof, and \( F \) is no. of degree of freedom.
2.2. Parallel manipulator control architecture

The control system is based on the microcontroller which is the center of all activity and is essentially an interpreter between the input and the hardware peripherals. All input data are sent to the microprocessor through input panel switches and all output peripherals are connected to microcontroller with required electronics components like liquid crystal display (LCD) units. As per the AHA standards, the requirements like compression depth, compression rate, and pause between the chest compressions are to be met by the developed system. The LCD indicator panel was powered by 9V AC/DC adapter for continuous display of compression depth, compression rate, and pause between the chest compressions. After performing 30 compressions the microcontroller stops sending signals to the relay for the pause time which is generally for providing two rescue breaths, and then starts sending signals to the solenoid for chest compressions. The program is written for ATMEGA16 microcontroller using embedded C++ programming language and built in the control system. The microprocessor used for this work is the AVR ATMEGA16. It is a general purpose microcontroller with a variety of peripheral ports such as analog-to-digital converters (ADC), bidirectional TTL input/output ports, and a USART interface to allow RS232 serial communication [15]. The original design of the embedded system hardware was to create a piece of hardware like a development board or kit. Fig. 2. shows the developed hardware control unit for parallel manipulator robot.

![Developed control unit for parallel manipulator robot.](image)

2.3. Experimental procedure

Experiments were conducted on Ambu® Cardiac Care Trainer System, made by Ambu A/S, Denmark. The Ambu manikin is equipped with the Ambu CPR-Software with a computer connection which provides various parameters during the CPR, these parameters include depth of compression, air volume and ECG profiles [16]. The software is designed to display the trainer’s performance and record the performance of one or multiple teams on one PC. The manikin can provide different chest stiffnesses ranging from 6 to 9 N/mm. The pneumatic pressure is varied from 4 to 7.5 bar. The experiments were conducted by varying the chest stiffness 0.5 N/mm for each 0.5 bar pneumatic pressure to get the required chest compression depth within the recommended ECG rate. The experimental setup showing the Ambu feedback manikin is in Fig. 3. Similarly, experiment is conducted manually using the two hands [17], here the position and orientation of the rescuer during manual CPR is shown in the Fig. 4.
3. RESULTS AND DISCUSSION

The outcomes of the experimental investigation were presented and briefly discussed in this section. As a first step, manual chest compressions were performed and later the parallel manipulator robot-based chest compressions were performed. The rescuer who was given CPR basic training by an ALS certified trainer in the Seesha Karunya Community Hospital (SKCH), Coimbatore performed the chest compressions on the sternum bone of the chest at a direction inclined to the sternum on a feedback manikin. The Fig. 5. shows the resulting poor quality of CPR showing inadequate depth and inappropriate duty cycle.
Figure 5 Performance of Manual chest compressions by a person weighing 60 kg.

In Fig. 5, the X-axis shows the simulation time and the Y-axis shows the depth of chest compression in millimeters. After 30 compressions, a pause is given for rescue breathing for a period of 2 seconds and once again the compression cycle begins. Leaning is occurred because of improper recoiling of the chest. Most of the compressions are over-depth due to excessive force applied by the rescuer. The chest compressions are not uniform, and the blood flow to brain will not be uniform. Fig. 6, shows the chest compressions performed by the proposed manipulator where each compression is falls between 50 to 60 mm depth as per the AHA recommendation for external chest compressions during CPR. Here, with the mechanical device the chest compression is observed to be in uniform and this helps in continuous flow of blood to the brain. And the table 1 gives the chest stiffness and depth of compression at various air pressures. The Fig. 7, Shows that the external chest compressions are within the recommendations of AHA, which are shown in the closed parenthesis.

Figure 6 Chest compressions by the proposed manipulator
Table 1 Chest Stiffness and Depth of Compression at various Air Pressure

<table>
<thead>
<tr>
<th>Chest stiffness (N/mm)</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
<th>5.5</th>
<th>6</th>
<th>6.5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>41</td>
<td>48</td>
<td>51</td>
<td>51</td>
<td>51</td>
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<td>6.5</td>
<td>42</td>
<td>46</td>
<td>49</td>
<td>48</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>35</td>
<td>39</td>
<td>46</td>
<td>48</td>
<td>48</td>
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<tr>
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<td>34</td>
<td>40</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>49</td>
</tr>
<tr>
<td>8.5</td>
<td>37</td>
<td>39</td>
<td>42</td>
<td>46</td>
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<td>40</td>
<td>46</td>
<td>47</td>
<td>47</td>
<td>47</td>
</tr>
</tbody>
</table>

The Fig. 8. shows the effect of pneumatic pressure on the depth of chest compression for chest stiffnesses varying from 6 N/mm to 9 N/mm. It is seen from the figure that the depth of compression increases as the pneumatic pressure increase. Since the depth of compression must be in the range of 50-60 mm, a pneumatic pressure of 5 bar or more is required for a chest stiffness of 6 N/mm. A pneumatic pressure of 6 bar or more is required for a chest stiffness of 6.5 N/mm. The depths of compression achieved for a chest stiffness of 7 N/mm or more under the range of pressures tested are not sufficient to meet the AHA 2010 guidelines. Either the pressure must be increased beyond 7.5 bar or the stroke length of pneumatic cylinders are to increase beyond 50 mm. The Fig. 9. shows that the depth of chest compression decreases with the increase in chest stiffness. The depths of compression for chest stiffness from 6 N/mm to 6.5 N/mm are acceptable as per AHA standards.
Usage of Parallel Manipulator For External Chest Compressions During Cardiopulmonary Resuscitation – An Experimental Study On Feedback Manikin

4. CONCLUSIONS

The complete description of the parallel manipulator showing dimensions is presented. The working principle of the manipulator is described. Through experiments, it is shown that CPR using a mechanical device results in chest compressions which are uniform which would result in continuous flow of blood to brain. It is shown that the hybrid manipulator used in this work is useful for conducting CPR on persons having chest stiffness of 6 to 6.5 N/mm when it is operated under a pneumatic pressure of 6 bar or more and the average depth of chest compression is 52 which is in between 50 to 60 as per the latest recommendations of American Heart Association guideline.

Fig. 8. Chest compression depths under different air pressures for various values of Chest stiffness.

Fig. 9. Depth of chest compression for different chest stiffness under a pneumatic pressure of 6 bar
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REFERENCES