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A STUDY ON ERGONOMIC EGG-SHAPED FOUR-BAR LINKAGE PROPULSION MECHANISM FOR MANUAL WHEELCHAIRS

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ABSTRACT

Most manual wheelchair users use conventional push-rim wheelchairs. Although manual push-rim wheelchairs help promotes a good lifestyle, the non-ergonomic, high muscular demand of non-continuous push motions can trigger severe upper extremity injuries.

In this study, a new four-bar linkage propulsion mechanism is introduced. The mechanism was designed to provide continuous propulsion while allowing the wrist movement to follow the ergonomic egg-shaped path. A prototype was built and tested. User opinions indicated that they experienced a more comfortable ride than in the conventional push-rim wheelchair. Overall, the use of the four-bar linkage mechanism causes less strain to muscles and should reduce fatigue during prolonged usages.

Disciplinary: Biomechanics/Biomedical Engineering, Mechanical Engineering, Medical Engineering Technology and Innovation.

1. INTRODUCTION

Ninety percent of manual wheelchair users use conventional push-rim wheelchairs for regular mobility and rehabilitation [1]. While manual push-rim wheelchairs help promotes healthy lifestyles, the non-ergonomic, high muscular demand, as well as non-continuous push motions can lead to acute upper extremity injuries [2]. Eighty-five percent of long time users of conventional wheelchairs (5-19 years) were found to suffer injuries to the tendons and muscles in the rotator cuff, deltoid, and long head muscle of the biceps brachii [3]. Even in light uses, a long period of rim contact during the push-rim stroke patterns can cause medial nerve injuries [4]. Moreover, the non-ergonomic movement often causes changes in the skeleton and muscle shapes, which in some cases cannot be healed [5].

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Many alternate manual propulsion mechanisms have been developed to improve the ergonomic. The major designs are lever drive [6] and hand cycle drive [7]. The use of lever drive provides a mechanical advantage, allowing wheelchairs to go through rough terrain with less effort. However, the arm movement is not continuous and the push-and-pull action is not comfortable for prolonged use. In another design, the use of a hand cycle drive allows continuous hand motion and provide mechanical advantage form chain reduction ratio. but it is still not ergonomic, because the effective drive range only occurs at 90-225 degrees and 270-30 degrees. It also increases the overall dimension of the wheelchair. Mixing of driving and steering action also makes it unpractical in many situations.

The new isokinetic propulsion system proposed by Babu et.al [8] was claimed to be the most ergonomic form of manual propulsion to date. The key to ergonomic is the dynamically optimized propulsion path of the wrist movement. The idea was developed into a working prototype [9], which employed a cam and belt mechanism to direct the wrists to move along the dynamically optimized path to propel the wheelchair.

In this study, a simple four-bar linkage propulsion mechanism was developed to create an ergonomic egg-shaped driving mechanism that closely follows the dynamically optimized propulsion path from [8]. Instead of using the complicated cam and belt mechanism. The following sections present design followed by force analysis, prototyping, and user test.

2. DESIGN

This section presents the mechanism design process to achieve an ergonomic driving path.

2.1 REFERENCE PATH

The dynamically optimized propulsion path suggested by Babu et al. [8] can be described by a set of parametric equations (1) and (2) that represents coordinate P_x and P_y on the path at any angle θ. A and B were constrained by the range of wrist motion. The optimized shape parameters are A = 151 mm, B = 152 mm and the shape factor n = 0.7.

$$P_x(\theta) = A \cdot \cos\theta \quad (1),$$

$$P_y(\theta) = B \cdot \sin\theta \sin\theta^n (0.5\theta) \quad (2).$$

According to [8], the dynamically optimized propulsion path was obtained by tilting the equations 15.9° clockwise. The final path looks like an egg shape as shown in Figure 1.

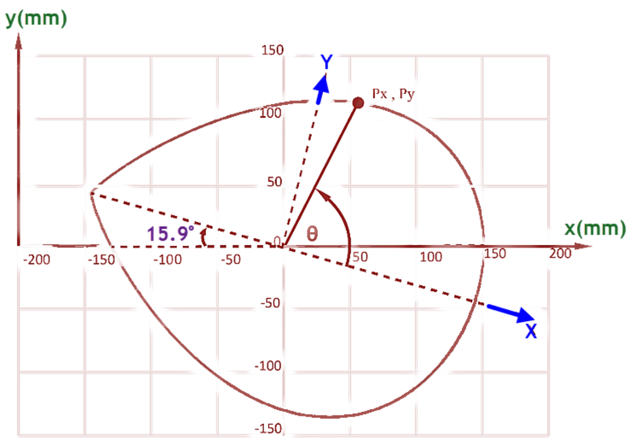

Figure 1: Dynamically optimized propulsion path (after [8]).

2.2 FOUR-BAR LINKAGE DESIGN

A four-bar linkage mechanism consists of base link **a**, input link **b**, follower link **d,** and coupler link **c**, see Figure 2. Variations of lengths of all links and position of a coupler point P on a coupler link, alter shapes of the tracked path, called coupler curves. Hrones and Nelson [10] presented atlas of approximately 7,300 coupler curves obtained from such variations. In fact, the number of coupler curves is infinite but limited in forms. In this study, the coupler curve will be used to guide the wrist movement along an ergonomic path to propel a wheelchair.

By adjusting the parameters of the mechanism, which consist of the lengths of links a, b, c and d, and the location coupler point P of the four-bar linkage mechanism in Figure 2, an ergonomic drive path can be achieved from the coupler curve of point P.

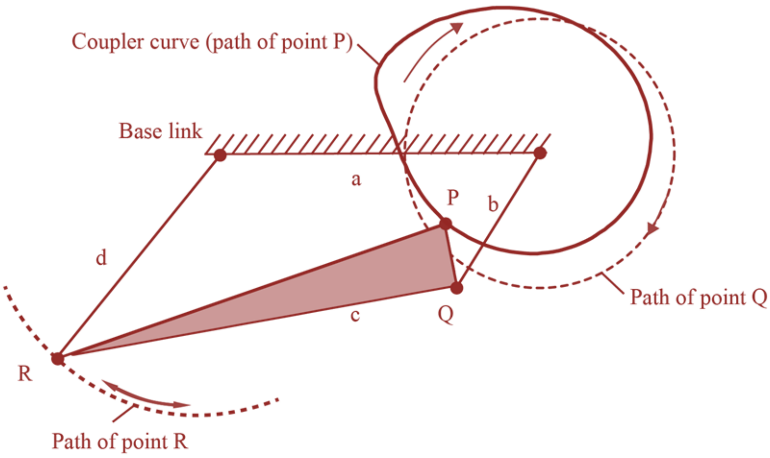

Figure 2: Four-bar linkage mechanism.

The parameters were adjusted to minimize the average difference between the coupler path of point P and the dynamically optimized propulsion path [8]. Figure 3 shows the final design of the mechanism that has the coupler curve matches the dynamically optimized propulsion path within 5%. Final values of the parameters are a = 321 mm, b = 138 mm, c = 339 mm, d = 198 mm, and location of point P as shown in the figure. This coupler path will be called an egg-shaped ergonomic drive path.

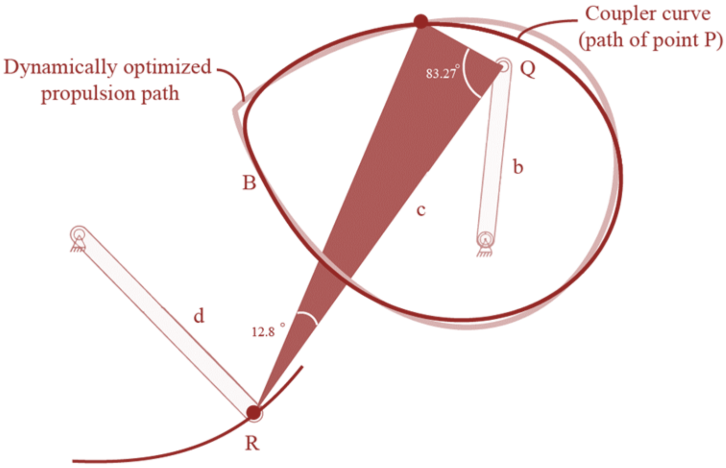

Figure 3: Final design four-bar mechanism.

2.3 PROPULSION MECHANISM DESIGN

From Figure 4, a handle is attached to point P to drive the mechanism so that the wrist of a user follows the egg-shaped ergonomic drive path. Being driven at point P, link b rotate in a full circle.

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Hence a drive sprocket was attached to the pivot point of link b. Power was then transmitted by the chain to the driven sprocket which is attached to the rear wheel of a wheelchair. From this point on the mechanism will be referred to as the EEF (Ergonomic Egg-shaped Four-bar linkage) propulsion mechanism.

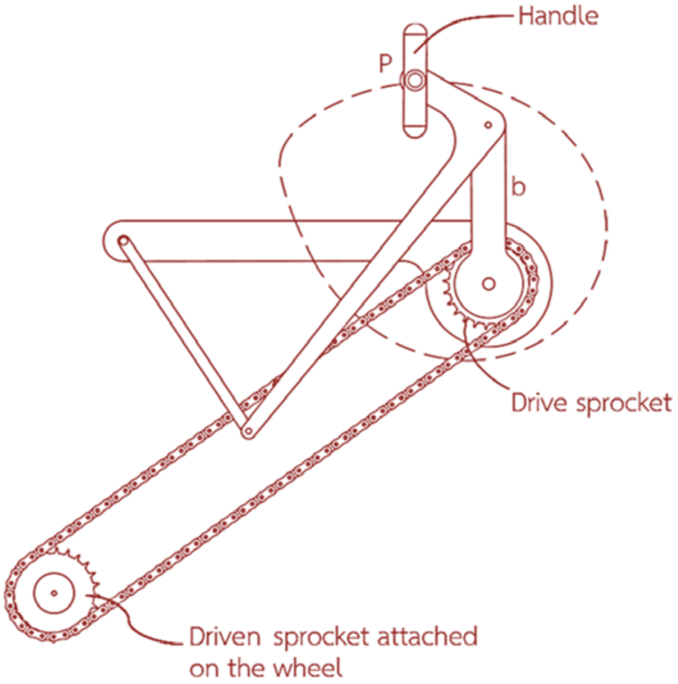

Figure 4: EEF propulsion mechanism.

Two ergonomic egg-shaped four-bar linkage propulsion mechanisms are then attached to the wheelchair on both left and right-hand sides, see Figure 5.

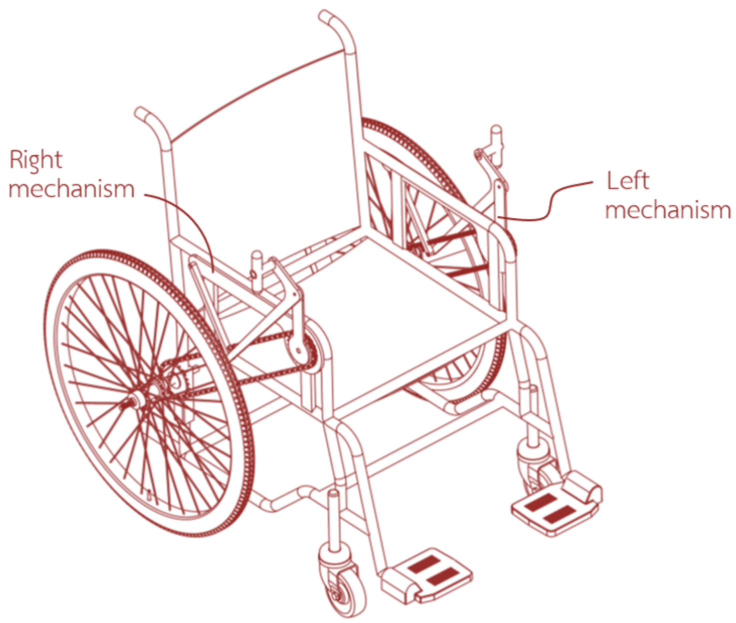

Figure 5: Installation of EEF propulsion mechanism to the wheelchair

The ergonomic egg-shaped path was located according to the suggested position form Babu et.al [8]. This makes a proper drive position as shown in Figure 6.

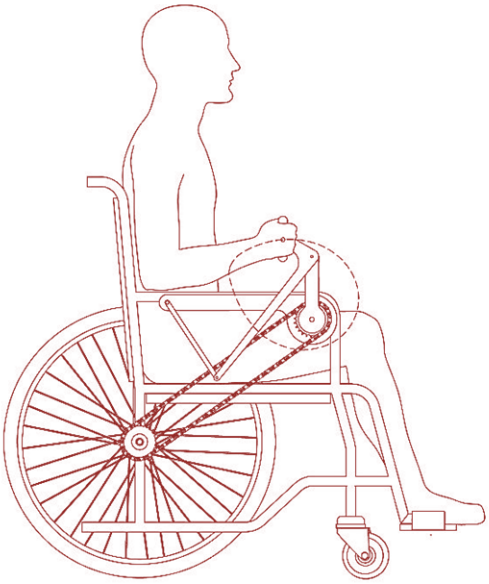

Figure 6. Right side view of the installation with the right rear wheel removed

3. PROTOTYPE AND TESTING

The prototype was developed by assembling the EEF propulsion mechanisms to both sides of a conventional push-rim wheelchair, as shown in Figure 7.

Figure 7: Prototype with EEF propulsion mechanisms on both sides of a conventional push-rim wheelchair.

It can be observed from Figure 8 that in the conventional wheelchair, at the start of the drive stroke, the lower arms make 60 degrees with a horizontal plane, whereas the required driving force is tangent to the wheel, in the horizontal direction. Hence there is a mechanical disadvantage. The user will have to push twice hander than necessary (form the 1/cos(60°) factor). In the wheelchair with the EEF propulsion mechanism, the upper arm angle is closely aligned with the required drive force along the egg-shaped ergonomic drive path, which results in a more efficient drive.

(a) (b)

Figure 8. Comparison of driving positions between a conventional push-rim wheelchair (a), and a wheelchair with EEF propulsion mechanism

Form the preliminary test, users found a more comfortable experience using the wheelchair with the EEF propulsion mechanism. They also indicated that the wheelchair needed less effort to propel and the arm positions are more natural and more comfortable.

4. CONCLUSION

An ergonomic egg-shaped four-bar linkage propulsion mechanism for a manual wheelchair was developed. A prototype was built and tested. The test results were positive. Users could achieve higher velocity than in the conventional wheelchair while using less effort. This encourages further study and development of the propulsion mechanism based on the prototype.

5. DATA AND MATERIAL AVAILABILITY

Information can be made available by contacting the corresponding author.

6. ACKNOWLEDGEMENT

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