The Innovative Design and Prototype Verification of Wheelchair with One Degree of Freedom to Perform Lifting and Standing Functions

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Abstract. Traditionally, the mechanism of wheelchair with lifting and standing functions has 2 degrees of freedom, and used 2 power sources to perform these 2 motion functions. The purpose of this paper is to invent new wheelchair with 1 degree of freedom to perform these 2 motion functions. Hence, we can use only 1 power source to drive the mechanism to achieve lifting and standing motion functions. The new design has the advantages of simple operation, more stability, and more safety. For traditional standing wheelchair, its center of gravity moves forward when standing up and it needs 2 auxiliary wheels to prevent dumping. In this paper, by using the checklist method of Osborn, the wheelchair with 1 DOF is invented to perform lifting and standing functions. The centre of gravity of this new wheelchair after standing up still located between the front and rear wheels, no auxiliary wheels needed. Finally, the prototype is manufactured to verify the theoretical results.

1. Introduction
Wheelchair is an important assisted vehicle for the disabled person for body moving and participating social activities. With the progress of sociality, the demands of wheelchair are more and more diversified. Hence, the standing up \cite{1-3}, lifting up \cite{4-6}, lying down \cite{7-9}, tilting down \cite{10-12}, and multi-function \cite{13-15} wheelchairs are invented to satisfy the disabled person’s need. Figs. 1(a) ~ 1(d) show the wheelchairs with standing, lifting, lying, and tilting functions. For a wheelchair with more than two functions is called multi-function wheelchair. This paper focuses on the innovative design of wheelchair with lifting and standing functions.

(a) Standing wheelchair \hspace{1cm} (b) Lifting wheelchair \hspace{1cm} (c) Lying wheelchair \hspace{1cm} (d) Tilting wheelchair

\textbf{Figure 1.} Functional wheelchairs
Currently, the mechanism of wheelchair with lifting and standing functions has 2 degrees of freedom, and used 2 power sources to perform these 2 motion function. The 1st purpose of this paper is to invent mechanism with 1 degree of freedom (DOF) to perform lifting and standing functions. Hence, we can use only 1 power source to drive the mechanism to achieve lifting and standing motion functions. According to Figure 1(a), for the traditional standing wheelchair, its’ centre of gravity moves forward when standing up and it needs 2 auxiliary wheels to prevent dumping. The 2nd purpose of this paper is to improve the above problem.

By referring to such related patents [1-15], the studies on kinematics of mechanisms [16-18], and the studies on the creative design [19-24], we synthesize a mechanism with 1 DOF to perform the lifting and standing functions. The centre of gravity of this new wheelchair after standing up and tilting down still located between the front and rear wheels, no auxiliary wheels needed. Hence, the new design has the advantages of simple operation, more stability, and more safety. The results of this research will enhance R&D capability in the multifunctional wheelchair to improve industrial competitiveness.

2. Multifunctional wheelchair

Before executing the innovative design, we have to collect and analyse the structure of multi-function wheelchairs including the mechanism from academic paper, catalogue, and technical report. Figure 2 shows a wheelchair, which is the product of AIDC, with standing and lying functions. Figure 3 shows a wheelchair, which is the product of LEVO, with standing and tilting functions. Figure 4 shows a wheelchair, which is the product of Sunrise Medical, with lifting and tilting functions.

![Figure 2. Wheelchair with standing and lying functions (AIDC)](image1)

![Figure 3. Wheelchair with standing and tilting functions (LEVO)](image2)
3. Osborn’s Check-List Method

Alex Faickney Osborn (May 24, 1888 – May 5, 1966) was an advertising executive and the author of the creativity technique named brainstorming. In 1953, Osborn published *Applied Imagination: Principles and Procedures of Creative Problem Solving*, in which Osborn presented the technique of *Check-List*. In the book “Applied Imagination”, Osborn listed 83 questions that could be used to check for creativity. Professor Dior of Harvard University summarized Osborn’s 83 questions to 9 items. The common 9 items are: 1. Reverse, 2. Transfer, 3. Combine, 4. Change, 5. Extend, 6. Enlarge, 7. Reduce, 8. Substitute, 9. Rearrange. When we use of Osborn check-list method to create new ideas and designs, we have to make sure that the creations could make advantages instead of just for invention. Therefore, we must make the innovation which can bring better performance than current status.

4. Innovative Design

Currently, the mechanism of wheelchair with lifting and standing functions has 2 degrees of freedom, and used 2 power sources to perform these 2 motion functions. The 1st purpose of this paper is to invent mechanism with 1 degree of freedom (DOF) to perform lifting and standing functions. According to figure 1(a), for the traditional standing wheelchair, its’ centre of gravity moves forward when standing up and it needs 2 auxiliary wheels to prevent dumping. The 2nd purpose of this paper is to improve the above problems. Here, we adopt the transfer, combine, and reduce methods of Osborn check list to design the wheelchair with lifting and standing functions.

4.1. Design Requirement

The requirements of the mechanism for wheelchair with standing and tilting functions are:

1. The mechanism of wheelchair has 1 degree of freedom.
2. The lifting and standing functions can be achieved by using only 1 power source.
3. The center of gravity of this new wheelchair after standing up still located between the front and rear wheels, no auxiliary wheels needed.

4.2. Transfer Method

The “transfer method” is to apply same ideas from other fields. It could be similar or totally different task. There are some old proverbs described the experience transfer, such as “The advice from others are better than 10-years studies.” and “The experience of others could be used as the reference.” “Transfer method” is not just to duplicate. It should not only absorb the essence from the other situation but also create a better idea and built a better result. Based on the transfer method, the brand new and practical invention could be realized.

Figure 5 shows a mechanism with 6 links and 7 joints (J1=7), its’ degrees of freedom can be written as:

\[ F = \lambda (N - J - 1) + \sum f_i = 3(6 - 7 - 1) + (7) = +1 \]  

(1)
Where, $\lambda$ is mobility number of mechanism (for planar mechanism, $\lambda=3$), $N$ is number of links, $J$ is Number of joints, and $\Sigma f_i$ is Total degrees of freedom of joints. The mechanism, shown in figure 5, has 1 degree of freedom and can achieve vertical lifting function.

4.3. Combine Method (1)

Many creative thinking processes involve the combination of different concepts. The “combine method” of Osborn check-list is to combine the different concepts for having the new creativity. The “combine method” has the following characteristics: 1. the effects of combining many individual concepts are greater than the sum of individual effects. 2. The cost of the combining many individual concepts is less than the sum of individual cost. Due to the reason that the follower of cam can move the prescribed motion, we combine the vertical lifting mechanism, shown in Fig. 5, and can pair to for designing wheelchair with lifting and standing functions. Figure 6 shows the corresponding combining process.

The temporary mechanism (I), shown in figure 6(c), has 6 links and 7 joints (including 1 cam pair g), i.e. $J_1=6$ and $J_2=1$, its’ degrees of freedom can be written as:

$$F = \lambda(N - J - 1) + \sum f_i = 3(6 - 7 - 1) + (6 + 2) = +2$$

This temporary mechanism (I), shown in figure 6(c), has 2 degrees of freedom. The temporary mechanism (I) does not meet the design requirements. So, the temporary mechanism (I) must be modified to have 1 degree of freedom.

4.4. Reduce Method

The “reduce method” of Osborn check-list is to lessen the fact, the appearance, or the significance of an existing design for having the new creativity. At this step, we use reduce method to reduce the
degrees of freedom of temporary mechanism (I). In the “reduce method”, slider 5 is eliminated and link 3 is adjacent to link 5 (seat 5) by revolute pair, figure 7 shows the corresponding reducing process.

The temporary mechanism (II), shown in figure 7(c), has 5 links and 6 joints (including 1 cam pair f), i.e. $J_1=5$ and $J_2=1$, its’ degrees of freedom can be written as:

$$F = \lambda(N - J - 1) + \sum f_i = 3(5 - 6 - 1) + (5 + 2) = +1$$

The temporary mechanism (II), shown in figure 7(c), has 1 degree of freedom.

4.5. Combine Method (II)

Due to the reason that temporary mechanism (II), shown in Fig. 7(c), does not have back link and foot link, we combine the temporary mechanism (II) and parallel four-bar linkage to obtain temporary mechanism (III). Figure 8 shows the corresponding combining process. The temporary mechanism (III), shown in figure 8(c), has 8 links and 10 joints (including 1 cam pair j), i.e. $J_1=9$ and $J_2=1$, its’ degrees of freedom can be written as:

$$F = \lambda(N - J - 1) + \sum f_i = 3(8 - 10 - 1) + (9 + 2) = +2$$

This temporary mechanism (III), shown in figure 8(c), has 2 degrees of freedom. The temporary mechanism (III) does not meet the design requirements

4.6. Enlarge Method

The “enlarge method” of Osborn check-list is to subjoin the fact, the appearance, or the significance of an existing design for having the new creativity. Due to the reason that the temporary mechanism (III) has 2 degrees of freedom, we must reduce its’ degrees of freedom to 1. At this step, we use“enlarge method” to reduce the degrees of freedom of temporary mechanism (III). In the“enlarge method”, link 9 is subjoined into the temporary mechanism (III) and adjacent to link 4 and link 8 by 2 revolute pairs (joints $k$ and $l$). Figure 9 shows the corresponding enlarging process. The new mechanism (IV) will
have 9 links and 12 joints (including 1 cam pair j), i.e. \( J_1 = 11 \) and \( J_2 = 1 \), its’ degrees of freedom can be written as:

\[
F = \lambda(N - J - 1) + \sum f_i = 3(9 - 12 - 1) + (11 + 2) = +1
\]  

(5)

The new mechanism (IV), shown in Figure 9(c), has 1 degree of freedom.

![Figure 9](image)

(a) Temporary mechanism (III)  (b) Binary link  (c) New mechanism (IV)

**Figure 9.** New mechanism (IV) obtained by “enlarge method”

4.7. **Combine Method (3)**

Due to the reason that the new mechanism, shown in figure 9(c), has 1 degree of freedom, we can arrange 1 power source to drive the mechanism to have the lifting and standing functions. At this last step, we use the “combine method” to combine the new mechanism and power source together. Figure 10 shows the corresponding combining process. The final mechanism will have 11 links and 15 joints (including 1 cam pair j), i.e. \( J_1 = 11 \) and \( J_2 = 1 \), its’ degrees of freedom can be written as:

\[
F = \lambda(N - J - 1) + \sum f_i = 3(11 - 15 - 1) + (14 + 2) = +1
\]  

(6)

The final mechanism, shown in figure 10(c), has 1 degree of freedom.

![Figure 10](image)

(a) New mechanism (IV)  (b) Power source  (c) Final mechanism

**Figure 10.** Final mechanism obtained by “combine method”

5. **Prototype Design and Manufacture**

According to Figure 10(c), the engineering drawings of the wheelchair are completed and its corresponding prototype is manufactured. Figures 11(a), 11(b), and 11(c) show the corresponding diagrams of multifunctional wheelchair at lower seat position, high seat position, and standing position. Figure 12(a), 12(b), and 12(c) shows the three situations of prototype of wheelchair with lifting and standing functions.
6. Conclusions
In this paper, we adopt the transfer, combine, and reduce methods of Osborn check list to invent “Wheelchair with One Degrees of Freedom to Perform Lifting and Standing Functions”. The results of this paper can be used as a reference for engineering to design the functional wheelchair and will enhance the industrial competitiveness. We conclude that this invention “Wheelchair with One Degrees of Freedom to Perform Lifting and Standing Functions” has following characteristics:
1. The mechanism of wheelchair is a mechanism with 1 degrees of freedom, it is driven by only 1 power source to drive the mechanism to achieve lifting and standing functions.
2. The center of gravity of this new wheelchair after standing up (or lifting up) still located between the front and rear wheels, no auxiliary wheels needed.
3. This invention has the advantages of simple operation, more stability, and more safety.

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