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The Systematic Design and Prototype Verification of the Wheelchair with Standing and Tilting Functions

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Keywords: multi-function wheelchair, scamper, standing function, tilting function.

ABSTRACT

Generally, the mechanism of "Wheelchair with Standing and Tilting Functions" has 2 degrees of freedom. In this paper, by using the checklist method (SCAMPER), the mechanisms with 1 DOF are invented to achieve the standing and tilting functions. Then, according to the dimensional synthesis, the dimensions of “Wheelchair with Standing and Titling Functions” are synthesized, the engineering design is accomplished, and the corresponding prototype is manufactured to verify the theoretical results. Two conclusions are derived as follows: (1). The new mechanisms invented have 1 degree of freedom (DOF) and use one power source to achieve the standing and tilting functions. (2). The centers of gravity of the new wheelchair after standing and tilting are still between the front and rear wheels, so no auxiliary wheels are needed.

INTRODUCTION

With the progress of sociality, the demands of wheelchair are more and more diversified. Hence, the standing, lifting, lying, tilting, and multi-function wheelchairs are invented to meet the need of the disabled people. For a standing wheelchair, the seat of the wheelchair will stand up and the user will have better blood circulation. For a tilting wheelchair, the seat of the wheelchair will rotate backward a certain angle (for example 30 degrees) and the user will relax the situation.

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For the traditional standing wheelchair, its’ center of gravity moves forward when standing and it needs 2 auxiliary wheels to prevent dumping. In addition, for tilting wheelchair, its’ center of gravity moves backward when tilting and it also requires 2 auxiliary wheels to prevent dumping. The 2nd focus of this paper is to improve the above issue.

Currently, the mechanism of "Wheelchair with Standing and Tilting Functions" has 2 degrees of freedom, and requires 2 power sources to perform these two motion functions. The 1st focus of this paper is to invent mechanism with 1 degree of freedom (DOF) that uses only 1 power source to achieve the standing and tilting functions.

Before executing the innovative design, we must collect and analyze the structure of multi-function wheelchairs from a wide variety of academic papers, catalogues, and technical reports. For the functional wheelchair, Park (2009) proposed a stand-up wheelchair, Huang (2013) invented a tilting mechanism for wheelchair, Bergman (2013) created a seat tilt apparatus, Hsieh and Wei (2013) proposed an electric wheelchair with sitting, lying, standing, and tilting postures, Wang *et al*. (2015) invented a multi-function wheelchair. Those patents can be used as references to creative wheelchairs with standing and tilting functions. Osborn (1953) published a book “Applied imagination”, in which Osborn presented the technique of *Check-List* that could be used to check for creativity. Altshuller (1988) presented 40 Principles for technical innovation. Yan (1998) proposed a creative design methodology for mechanism design. Hsieh *et al*. (2012, 2013, and 2017) used above creative techniques to invent new designs including quick folding bicycle with high rigidity, automatic transmissions for electric motorcycles, and wheelchair with lifting and standing functions. By referring to above patents and creative design methodology, 28 mechanisms with 1 DOF are created. Mabie and Reinholtz (1987) published a book “Mechanisms and Dynamics of Machinery”, Yan (2016) published a book “Mechanisms: Theory and Applications”. According to the textbook of mechanisms, Hsieh *et al*. (1996, 2007, and 2012) designed the mechanisms for specified purpose including south pointing chariots, Ellipsograph Mechanisms, and link-type optical fiber polisher. Then, based on the kinematics of mechanisms, the dimensions of a wheelchair with standing and tilting functions are synthesized. The center of gravity of this new wheelchair is still between the front and rear wheels while standing and tilting, as the results, no auxiliary wheels are needed. It's been concluded that the new design proposed in this paper has the advantages of an easy operation, high stability, and high safety.

FUNCTIONAL WHEELCHAIRS

1. Single-function wheelchairs

With the progress of sociality, the demands of wheelchair are more and more diversified. Hence, wheelchairs with the standing, lifting, lying, and tilting functions are invented to meet the need of the disabled people. Fig. 1(a) shows the standing wheelchair, which can help the disabled people reach the standing position to promote blood circulation and gastrointestinal motility, improve constipation, reduce muscle atrophy, slow down osteoporosis, and increase the quality of life. In the psychology of the disabled people, a standing wheelchair can also help the disabled improve their communication with people and boost up their confidence. Fig. 1(b) shows the lifting wheelchair, which can help the disabled people overcome the psychological pressure of lower compared to the average person and build up their confidence. Fig. 1 (c) shows a lying wheelchair that can be changed from a sitting posture to a lying posture so that the user can lie down and rest at any time in the wheelchair for comfort. Fig. 1(d) shows the tilting wheelchair, which is the focus of functional wheelchairs in recent years and has backward tilting angle about 20~30 degrees. The tilting wheelchair can help the disabled people achieve a short break, reduce the production of hemorrhoids, relax the muscle fatigue, and improve the blood circulation.

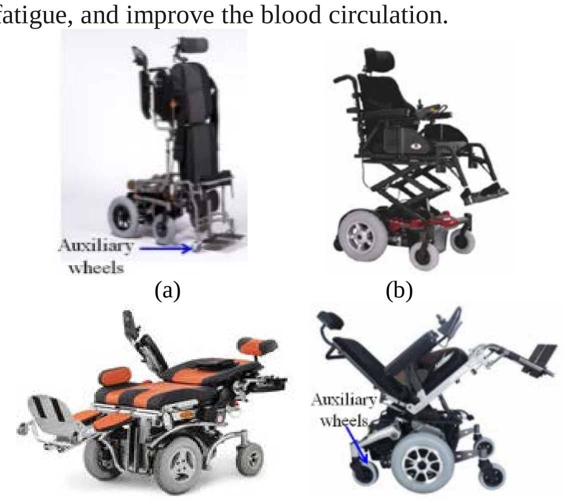


Fig. 1. Single functional wheelchairs: (a) Standing wheelchair; (b) Lifting wheelchair; (c) Lying wheelchair; (d) Tilting wheelchair

2. Standing wheelchairs

For standing wheelchair, the seat of the wheelchair will stand up and the user will have better blood circulation. Fig. 2(a) shows the standing wheelchair, which is the product of Vermeiren company, Belgium [21]. Fig. 2(b) shows the standing wheelchair, which is the product of Meyra company, Germany [22]. Fig. 2(c) shows the standing wheelchair, which is the product of AIDC company, Taiwan [23]. Fig. 2(d) shows the standing wheelchair, which is the product of Karma company, Taiwan [24]. For achieving standing functions, all of them have the same mechanism, shown in Fig. 3, and 2 auxiliary wheels are used to prevent dumping when standing.

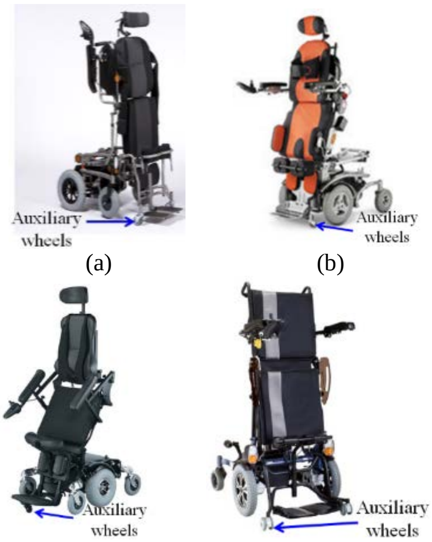


Fig. 2. Standing wheelchairs: (a) Vermeiren; (b) Meyra; (c) AIDC; (d) Karma

The mechanism, shown in Fig. 3, is a mechanism with 6 links and 7 joints (including 6 revolute pairs and 1 prismatic pair), i.e. J_1=7, its' degrees of freedom can be calculated as:

$$F = 3(\mathrm{N}-\mathrm{J}-1)+\sum_{i=1}^{J} f_i = 3(6-7-1)+(7)=1 \quad (1)$$

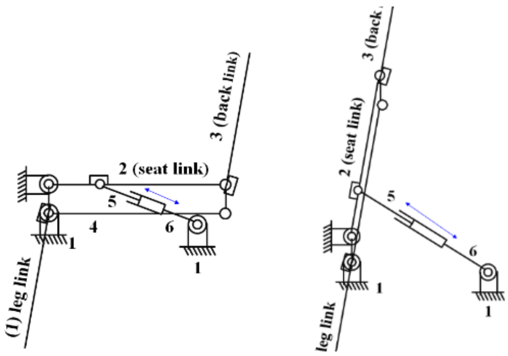


Fig. 3. Mechanism having standing function: (a) Sitting posture; (b) Standing posture

where N is the number of links, J is the number of joints, and Σf_i is total degrees of freedom of all joints. The mechanism, shown in Fig. 3, has 1 DOF in which the link 5 and the link 6 constitute an actuator and serve as an input.

3. Titling wheelchairs

For tilting wheelchair, the seat of the wheelchair will rotate backward a certain angle (for example 30 degrees) and the user will relax the situation. Fig. 4(a) shows the tilting wheelchair, which is the product of Vermeiren company, Belgium [21]. Fig. 4(b) shows the tilting wheelchair, which is the product of Meyra company, Germany [22]. Fig. 4(c) shows the tilting wheelchair, which is the product of Karma company, Taiwan [24]. Fig. 4(d) shows the tilting wheelchair, which is the product of the Sunrise Medical company, Germany [25]. According to Figs. 4(a) ~ 4(d), two mechanisms, as shown in Figs. 5 and 6, are used to achieve the tilting function, and all tilting wheelchairs have 2 auxiliary wheels to prevent dumping while tilting.

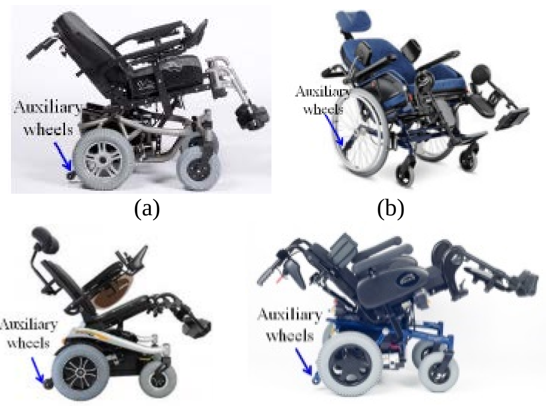
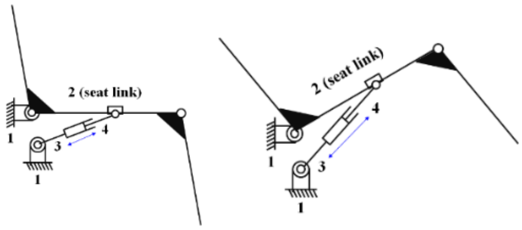


Fig. 4. Tilting wheelchairs: (a) Vermeiren; (b) Meyra; (c) Karma; (d) Sunrise Medical

The mechanisms, shown in Figs. 5 and 6, are mechanisms with 4 links and 4 joints (J_1=4), their degrees of freedom can be calculated as:

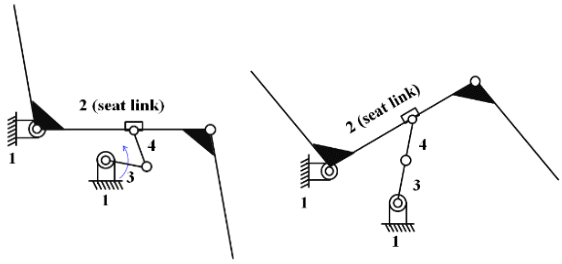
$$F = 3(\mathrm{N}-\mathrm{J}-1)+\sum_{i=1}^{J} f_i = 3(4-4-1)+(4) = 1 \qquad (2)$$

The mechanisms, shown in Figs. 5 and 6, have 1 DOF. For the mechanism shown in Fig. 5, link 3 and the link 4 constitute an actuator and serve as an input. For the mechanism shown in Fig. 6, link 3 is the input link and driven by an electric motor.



(a) (b)

Fig. 5. The mechanism (I) having tilting function: (a) Sitting posture; (b) Tilting posture



(a) (b)

Fig. 6. The mechanism (II) having tilting function: (a) Sitting posture; (b) Tilting posture

The mechanisms, shown in Figs. 5 and 6, have 1 DOF. For the mechanism shown in Fig. 5, link 3 and the link 4 constitute an actuator and serve as an input. For the mechanism shown in Fig. 6, link 3 is the input link and driven by an electric motor.

4. Wheelchair with standing and tilting functions

For a wheelchair with more than two functions is called a multi-function wheelchair. Fig.7 shows a wheelchair, which is the product of LEVO company, Switzerland [26], with standing and tilting functions. The mechanism, shown in Fig. 7, has 2 degrees of freedom, and uses 2 power sources to perform these 2 motion functions. The purpose of this paper is to invent a mechanism with 1 DOF to achieve the standing and tilting functions.

(a) (b)

Fig. 7. Wheelchair with standing and tilting functions (LEVO): (a) Standing posture; (b) Tilting posture

INNOVATIVE DESIGN

The checklist is the simplest method for problem solving. It solves the problem by checking the prepared list item. In innovative design process, a checklist is a set of questions that can be asked to stimulate different ideas. In 1953, Osborn, originator of creativity techniques, listed 83 questions in his book "Applied Imagination" for creating new things. Robert F. Eberle summarized Osborn's 83 questions to 7 items (SCAMPER): 1. S: Substitution, 2. C: Combination, 3. A: Adaptation, 4. M: Magnification, or Modification, 5. P: Put to other uses, 6. E: Elimination and Minification, 7. R: Reverse and Rearrange.

When creating a new design by using the checklist method, you must ensure that the new innovations lead to better results. In this paper, we use the checklist method to design new wheelchairs with standing and tilting functions.

1. Design Requirements and Design constraints

The design requirements and design constraints of the wheelchair with standing and tilting functions are:

(1) The mechanism of a wheelchair has 1 degree of freedom.

(2) When at standing posture, the seat link rotates counterclockwise 80º (θ_s=80º).

(3) When at tilting posture, the seat link rotates clockwise 30º (θ_t=-30º).

(4) The standing and tilting functions can be achieved by using only 1 power source.

(5) The center of gravity after standing and tilting will still be located between the front and rear wheels, no auxiliary wheels are needed.

2. Adaptation Method

The "adaptation method" is to apply the solution of other fields for our design case. It is not only to absorb the essence of other design cases, but also to create better designs and results. New and practical inventions could be realized by using the "adaptation method". Fig. 8 shows a slider-crank mechanism, having tilting, sitting, and standing postures, which can be adapted for designing the wheelchair with tilting and standing functions.

Fig. 8 shows a slider-crank mechanism, which has 4 links and 4 joints (including 3 revolute pairs and 1 prismatic pair), i.e. J_1=4, its' degrees of freedom can be calculated as:

$$F = 3(N - J - 1) + \sum_{i=1}^{J} f_i = 3(4-4-1) + (4) = 1 \qquad (3)$$

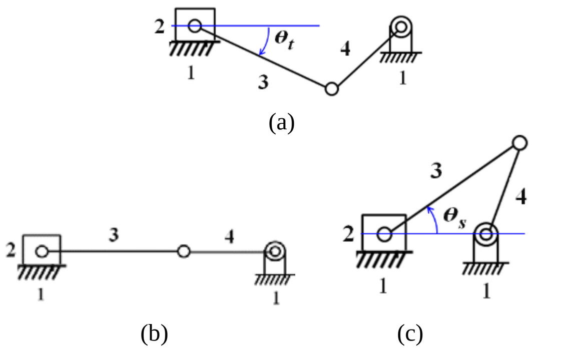


Fig. 8. Slider-crank mechanism: (a) Tilting posture; (b) Sitting posture; (c) Standing posture

The crank slider mechanism, shown in Fig. 8, has one degree of freedom and does not meet the design requirements and design constraints, and therefore needs to be modified. In this paper, the slider-crank mechanism is adapted and modified as the "eccentric slider-crank" for the designing wheelchair with tilting and standing functions. Figs. 9(a), 9(b), and 9(c) show that the connecting link (3) of "eccentric slider-crank" is switched from the tilting posture to the sitting posture and the standing posture. It is concluded that the "eccentric slider-crank", shown in Fig. 9, which can meet the design requirements and design constraints.

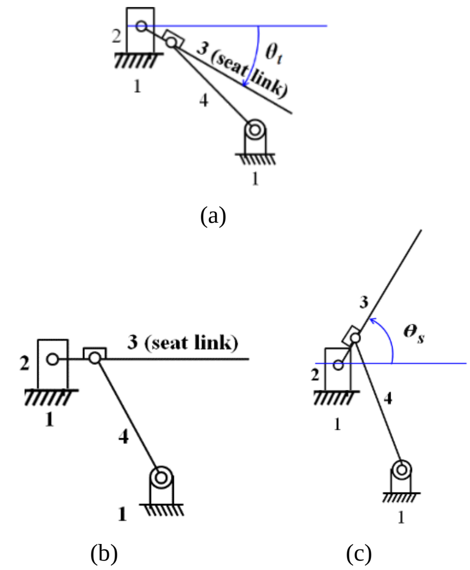


Fig. 9. Eccentric slider-crank mechanism for achieving tilting and standing functions: (a) Tilting posture; (b) Sitting posture; (c) Standing posture

3. Combination Method (I)

The "combination method" is to combine different solutions in order to obtain new solutions. It has the following features: 1. The effects of combining are greater than the sum of individual effects. 2. The cost of the combining is less than the sum of the individual costs.

For the mechanism of “Wheelchair with Standing and Tilting Functions”, it includes not only the seat link but also the back link and the leg link, so that the "eccentric slider-crank" and the "parallel four-link" were combined together to **get** a temporary mechanism (I), as shown in Fig. 10. The temporary mechanism (I), shown in Fig. 10, has 7 links and 8 joints (including 7 revolute pairs and 1 prismatic pair), i.e. J_1=8, its’ degrees of freedom can be calculated as:

$$F = 3(N - J - 1) + \sum_{i=1}^{J} f_i = 3(7 - 8 - 1) + (8) = 2 \quad (4)$$

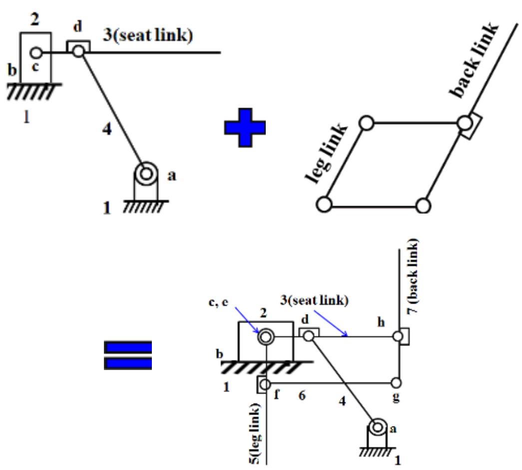


Fig. 10. Temporary mechanism (I) obtained by “combination method (I)”

4. Magnification Method

The “Magnification method” is to enlarge (or integrate) the things, principles, or ideas for the creation of the new design. Due to the reason that the temporary mechanism (I) has 2 degrees of freedom, it must be reduced to 1 degrees of freedom. Here, a binary link was integrated into the temporary mechanism (I) to reduce its degrees of freedom. In this step, binary link 8 was subjoined into the temporary mechanism (I) and adjacent to link 2 and link 7 by 2 revolute pairs (joints *i* and *j*). Fig. 11 shows the corresponding magnifying process. The temporary mechanism (II) has 8 links and 10 joints (including 9 revolute pairs and 1 prismatic pair), i.e. J_1=10, its’ degrees of freedom can be calculated as:

$$F = 3(N - J - 1) + \sum_{i=1}^{J} f_i = 3(8 - 10 - 1) + (10) = 1 \quad (5)$$

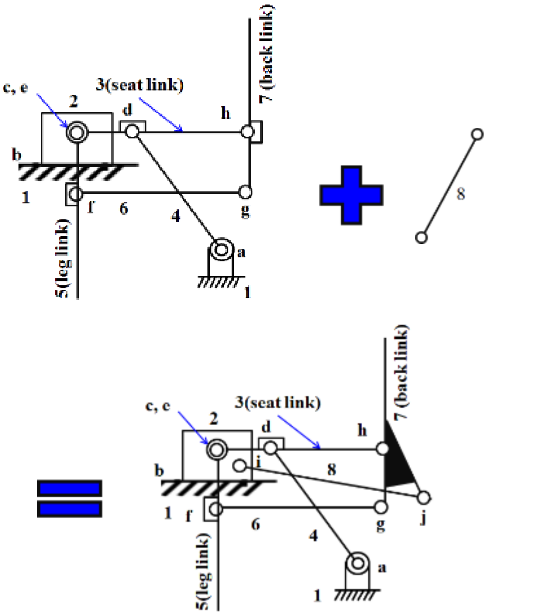


Fig. 11. Temporary mechanism (II) obtained by “magnification method”

5. Combination Method (II)

Since, the temporary mechanism (II) shown in Fig. 11 has one degree of freedom, the power source (link 9 and link 10) and the temporary mechanism (II) can be combined together to get a new mechanism of "wheelchair with Standing and Tilting Functions", as shown in Fig. 12. According to the combining process shown in Fig. 12, there are $C_2^8 = (8 \times 7)/2 = 28$ possible new designs. The final new mechanisms, as shown in Fig. 13, have 10 links and 13 joints (including 12 revolute pairs and 1 prismatic pair), i.e. J_1=13, its’ degrees of freedom can be calculated as:

$$F = 3(N - J - 1) + \sum_{i=1}^{J} f_i = 3(10 - 13 - 1) + (13) = 1 \quad (5)$$

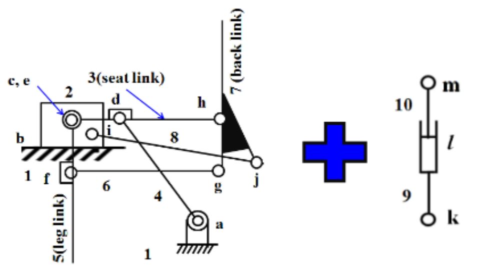
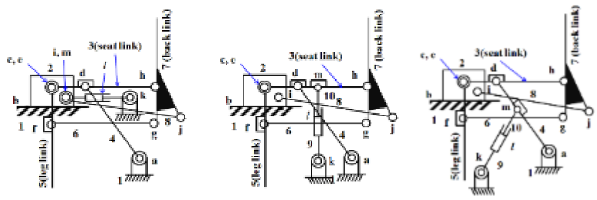


Fig. 12. Last step: “combination method (II)” for creating new mechanisms



(a) (b) (c)

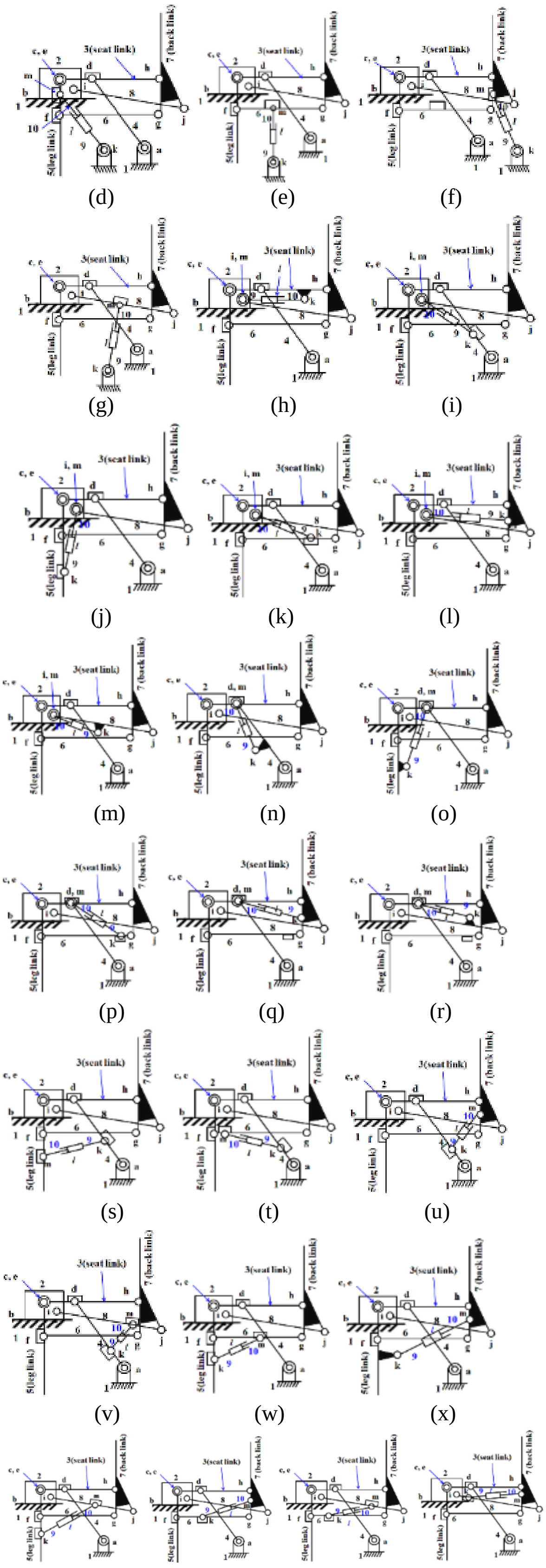


Fig. 13. New mechanisms having standing and tilting functions

GIMENSIONAL SYNTHESIS

In this section, the design concept, shown in Fig. 13(b), is chosen for the engineering design and prototype manufacture. Here, the innovative mechanism of Fig. 13(b) is redrawn and shown in Fig. 14. In the following, its dimensional synthesis of wheelchair with standing and tilting functions are introduced.

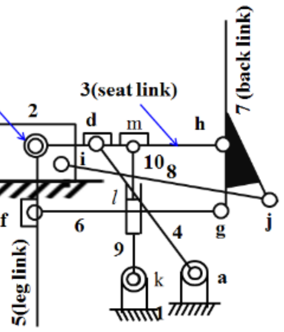
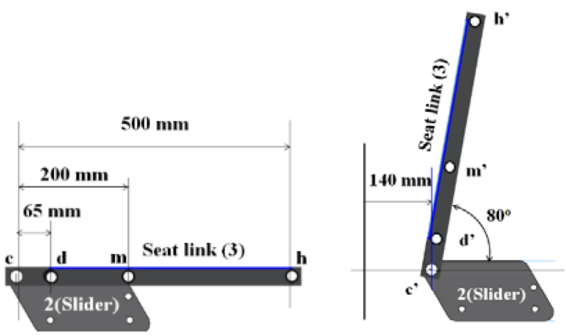


Fig. 14 The design concept for the engineering design and prototype manufacture

1. Eccentric slider-crank

The 1st step of dimensional synthesis is to determine the length of the seat link (3). In this paper, the link length of seat link (3) is designed to be 500 *mm*, as shown in Fig. 15(a). Then, the angles of the seat link of three postures must be confirmed. When the slider (2) moves right 140mm, the seat link (3) will rotate 80°, Fig. 15(b) shows the corresponding standing posture. When the slider (2) moves left 200mm, the seat link (3) will rotate -30°, Fig. 15(c) shows the corresponding tilting posture. Fig. 15(d) shows the result of combining the above three postures together. In Fig. 15(d), the line $\overline{N_1N_1}$ is a mid-perpendicular line of line segment $\overline{dd'}$, the line $\overline{N_2N_2}$ is a mid-perpendicular line of line segment $\overline{dd''}$, and the intersection of line $\overline{N_1N_1}$ and line $\overline{N_2N_2}$ is the location of fixed pivot (*a*) of crank (4). Fig. 15(e) shows the dimensions of eccentric slider-crank.



(a) (b)

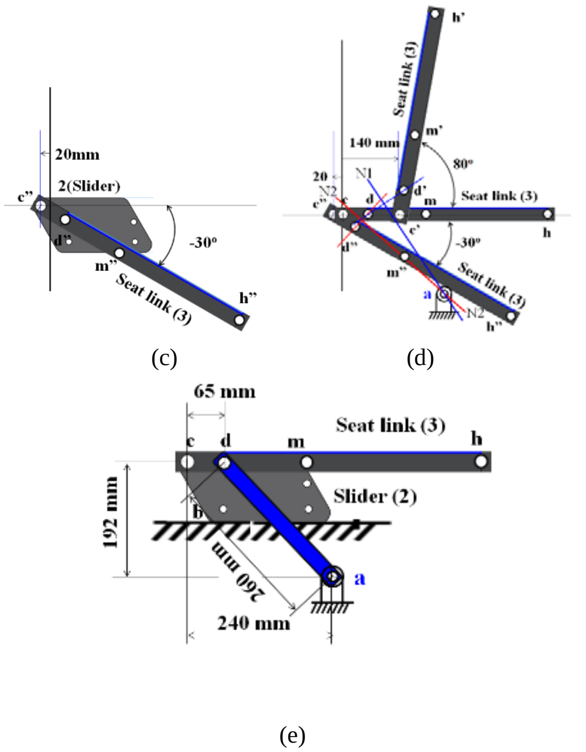


Fig. 15. The dimensional synthesis of eccentric slider-crank: (a) Sitting posture; (b) Standing posture; (c) Tilting posture; (d) 3 postures; (e) Dimensions of eccentric slider-crank

2. Location of joint (i)

The 2nd step of dimensional synthesis is to determine the location of revolute joint (i) and length of link 8. When the seat link (3) is tilted backward, back link (7) is subjected to bear a large force. Hence, a diagonal rod is added for reinforcement, Fig. 12(a) shows the dimensions of back link (7). Then, the angles between seat link (3) and back link (7) of the three postures must be confirmed.

(1) For sitting posture, shown in Fig. 16(a), the angle between seat link (3) and back link (7) is 100°.
(2) For standing posture, shown in Fig. 16(b), the angle between seat link (3) and back link (7) is 170°.
(3) For tilting posture, shown in Fig. 16(c), the angle between seat link (3) and back link (7) is 120°.
(4) Fig. 16(d) shows the result of combining the above three postures together.

In Fig. 16(d), the line $\overline{N_1N_1}$ is the mid-perpendicular line of line segment $\overline{jj'}$, the line $\overline{N_2N_2}$ is the mid-perpendicular line of line segment $\overline{jj''}$, and the intersection of line $\overline{N_1N_1}$ and line $\overline{N_2N_2}$ is the location of joint (*i*). Fig. 15(e) shows the location of joint (*i*) and length of the link 8.

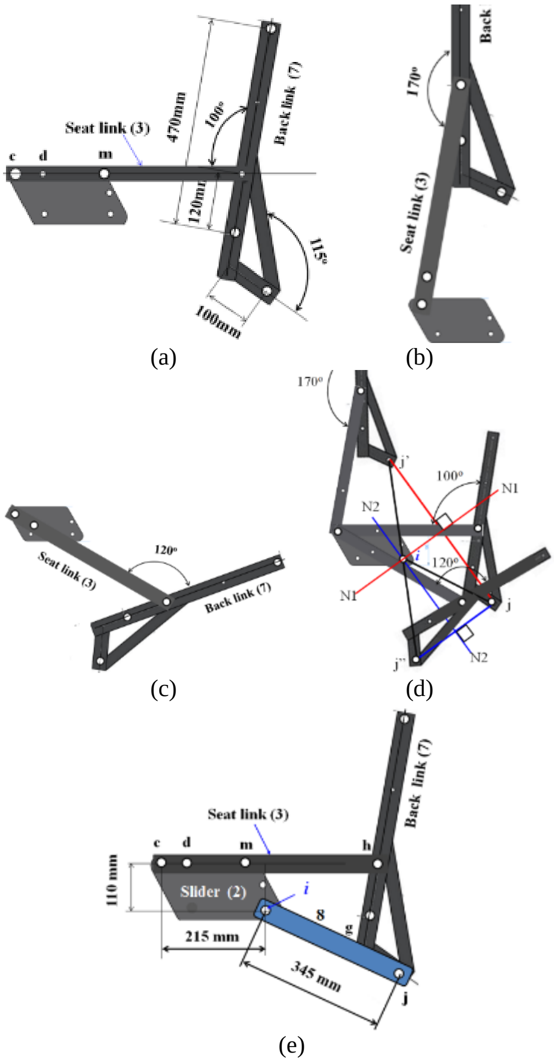
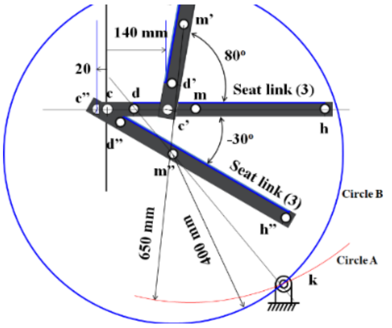


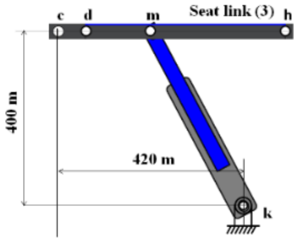
Fig. 16. The determination of the location of joint (i): (a) Sitting posture; (b) Standing posture; (c) Tilting posture; (d) 3 postures; (e) Location of joint (i) and the length of link 8

3. Location of joint (k)

The 3rd step of dimensional synthesis is to determine the location of joint (k) for power source. Link 9 and link 10 constitute an electric actuator, which has the shortest length of 400mm, longest length of 650mm, and stroke of 250mm. In Fig. 17(a), the circle (A) is a circle having a radius of 650mm with center point of m', and the circle (B) is a circle having a radius of 400mm with center point of m", and point (k) is the intersection of these two circles. Fig. 17(b) shows the power source and its location of joint (k).



(a)

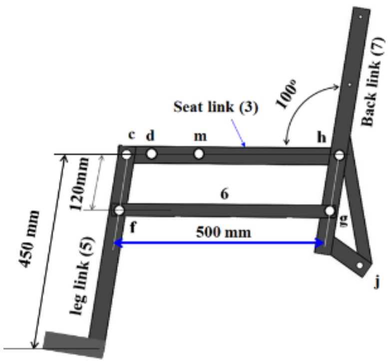


(b)

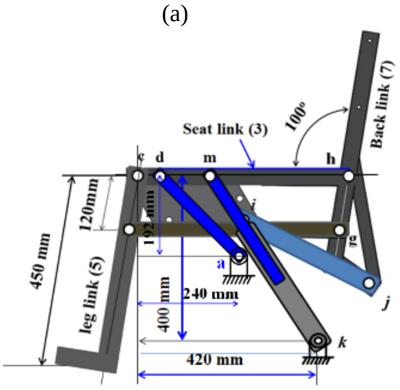
Fig. 17. The determination of the location of joint (k): (a) 3 postures and the determination of joint (k); (b) Location of joint (k)

4. Parallel four-bar linkage (back and leg links)

The final step of dimensional synthesis is to identify the dimensions of parallel four-bar linkage as shown in Fig. 18(a). Then, according to the above results, all dimensions of the mechanism with standing and tilting functions are shown in Fig, 18(b).



(a)

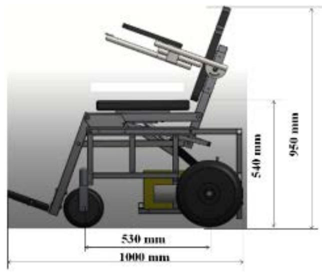


(b)

Fig. 18. All dimensions of the new mechanism: (a) Parallel four-bar linkage; (b) All dimensions of the new mechanism

ENGINEERING DESIGN AND PROTOTYPE MANUFACTURE

According to the results of dimensional synthesis, shown in Fig. 18(b), the engineering drawings of the multi-function wheelchair are completed. Figures 19(a), 19(b), and 19(c) show the side views of engineering design of the multi-function wheelchair at sitting posture, standing posture, and tilting posture. Figs. 20(a), 20(b), and 20(c) show the isometric views of engineering design of the multi-function wheelchair at sitting posture, standing posture, and tilting posture. And, Figs. 21(a), 21(b), and 21(c) show the isometric photos of the prototype of the multi-function wheelchair at sitting posture, standing posture, and tilting posture.



(a)

(b) (c)

Fig. 19. Side views of the wheelchair with standing and tilting functions: (a) Sitting posture; (b) Standing posture; (c) Tilting posture

(a)

(b) (c)

Fig. 20. Isometric views of the wheelchair with standing and tilting functions: (a) Sitting posture; (b) Standing posture; (c) Tilting posture

(a)

(b) (c)

Fig. 20. Isometric photos of the prototype with standing and tilting functions: (a) Sitting posture; (b) Standing posture; (c) Tilting posture

CONCLUSIONS

In this paper, the adaptation, combination, and magnification methods of “SCAMPER” was adopted for creating new designs of “Wheelchair with Standing and Tilting Functions”, and 28 new mechanisms were invented. It’s been concluded that this invention “Wheelchair with Standing and tilting Functions” has the following characteristics:

1. The new mechanisms have 1 DOF and use one power source to achieve the standing and tilting functions.
2. The centers of gravity of the new wheelchair after standing and tilting are still between the front and rear wheels, so no auxiliary wheels are needed.
3. This invention has the advantages of simple operation, more stability, and more safety.

The results of this paper can be used for further reference in the engineering field in order to design a better functional wheelchair and will also enhance the industrial competitiveness.

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具站立和後傾功能輪椅之系統化設計與雛型驗證

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摘 要

一般而言,“具站立和後傾功能輪椅”的機構具有2個自由度。本研究，首先利用檢核表中之（SCAMPER）方法，創造出可實現站立和後傾功能之1個自由度的機構；接著根據尺寸合成理論，合成出“具有站立和後傾功能之輪椅”的尺寸,並完成工程設計與雛型機製作，驗證理論結果。 本研究成果如下：

(1).本研究創造出可實現站立和後傾功能之1個自由度的機構，並使用一個動力源來實現站立和後傾功能。

(2).本發明“具有站立和後傾功能之輪椅”，當站立和傾斜時，輪椅的重心仍然位於前輪和後輪之間，因此不需要額外的輔助輪。