The Design and Kinematic Analysis of Multi-function Rehabilitation Bed Based on Double Rocker Mechanism

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ABSTRACT

In view of the increasing demand for rehabilitation nursing service resulting from aging population, a new type of rehabilitation bed system is put forward. The main components consisting of double rocker support, auxiliary spring support, back lifting and leg bending mechanisms, and drive device to realize automatic walk and obstacle avoidance, are introduced. Based on the simplified structural model of leg bending mechanism, the kinematic equations are established and solved to analyze and evaluate stability and safety of posture transformation. The different position transformations of virtual prototype are described to illuminate its principle. The bed scheme has characteristics of being compact, multiple function and easy adjustment, aiming to help the patients and olds to live on their own and to promote health recovery.1

INTRODUCTION

With the continuous growth of population, the aging of population has been a problem that many countries in the world have to face. The injured and sick weakness group unable to live by themselves is becoming bigger and bigger on account of an increasing population base. As a result, the daily nursing work of those people has become an inevitable problem for society [1].

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The rehabilitation nursing work can be carried out either with the help of family members and nursing staffs or by means of nursing facilities such as rehabilitation bed. At present, the existing rehabilitation beds have the defects of structure being big, motion of inconvenience and operation lack of flexibility, and many bed systems do not have a standing function[2]. Therefore, a new multi-function rehabilitation bed system is put forward based on this social situation and the advantages and disadvantages of existing bed systems, which can realize automatic walk and obstacle avoidance powered by electric cylinders and motors.

**SYSTEM PLAN OF REHABILITATION BED**

The rehabilitation bed system belongs to a three-fold bed system, and its posture transformation can be achieved with the rotation of bed’s different structural modules through hinge axes, the bed’s structure is as shown in figure 1.

The structural scheme is designed based on functional demands, and the structural system consists of bed structure, double rocker support, spring support, leg bending, collapsible guard bar, drive system, lid’s open and close structure, salver support mechanisms and so on, the structure scheme is as shown in figure 2.

The rehabilitation bed system is mainly made up of two parts one of which is mechanical structure system and the other is electrical control system. The bed’s walk, obstacle avoidance and electric cylinder’s extending and shrinking motions can be performed by controlling motors’ speed and rotational direction with some executive and sensor components [3-4]. The control system is as shown in figure 3.

![Figure 1. Schematic diagram of rehabilitation bed.](image-url)
DESIGN AND ANALYSIS OF REHABILITATION BED

The integral structural size of rehabilitation bed, referring to industry standard of medical device and ergonomic theory, is designed to be length×width×height =1900×600×620 mm and the fold angle of each bed’s plate is that the upper bed plank: 0°~65, the lower bed plank: 0°~60°, and the pedal plate: 120°~180°, based on the referable parameters of human body and actual simulation experiments.

Design and Analysis of Leg Bending Structure

Considering the fact that the range of angle is constrained by industry criterions, the kinematic analysis model of leg bending mechanism is necessarily established to lay the parameter foundations of following 3D modeling work, as shown in figure 4.

According to the geometric knowledge in mathematics, the kinematic equations can be gotten as the following:

\[
\begin{align*}
O_{A}=l_{1};OC=l_{2};CB=l_{3}; \quad B(\pm r\cos\frac{\pi}{3},l_{2}\sin\frac{\pi}{3})-l_{3}; \quad B'=\frac{1}{2}(OB+OB)=\left(\frac{3}{4}l_{2}+\frac{1}{4}l_{r},\frac{2+\sqrt{3}}{4}l_{3}+\frac{\sqrt{3}}{4}l_{1}\right); \quad \frac{BB'}{B}=(\frac{\sqrt{2}}{2}l_{2},\frac{1}{2}l_{r},\frac{\sqrt{3}}{2}l_{2}+\frac{\sqrt{3}}{2}l_{1}); \quad B'A=(\frac{\sqrt{2}}{2}l_{2},\frac{1}{2}l_{r},\frac{\sqrt{3}}{2}l_{2}+\frac{\sqrt{3}}{2}l_{1}); \quad \overline{BB'}/\overline{B'A}=\rightarrow \overline{BB'} \cdot \overline{B'A}=0
\end{align*}
\]

With the initial parameters such as \(L_{2} = L_{2} = r_{3} = 465 \text{ mm}\) and \(L_{3} = L_{3} = r_{2} = 100.54 \text{ mm}\), the solutions can be gotten as \(r = r_{1} = 521.82 \text{ mm}\) and \(L_{1} = L_{1} = r_{4} = 150.93 \text{ mm}\) on the platform of MATLAB software.
Kinematic Analysis of Leg Bending Structure

The kinematic characteristic of leg bending structure has an effect on the comfort of transformation so that it is also necessary to make structural model to explore the speed characteristic. The structural model is as shown in figure 5.

According to the closed loop vector equation and Euler formula, the equations can be gotten as following:

1. Vector equations:

\[
\begin{align*}
    r_2 + r_1 &= r_3 + r_4 \\
    r_2 e^{\theta_2} + r_1 e^{\theta_1} &= r_3 e^{\theta_3} + r_4 e^{\theta_4}
\end{align*}
\]

2. Equations of angular displacement:

\[
\begin{align*}
    r_2 \cos \theta_2 + r_1 \cos \theta_1 &= r_3 \cos \theta_3 + r_4 \cos \theta_4 \\
    r_2 \sin \theta_2 + r_1 \sin \theta_1 &= r_3 \sin \theta_3 + r_4 \sin \theta_4 \\
    \theta_4 \text{ - constant} \quad \theta_4 &= 225^\circ
\end{align*}
\]

3. Matrix equations of angular velocity:

\[
\begin{bmatrix}
    -r_2 \sin \theta_2 & r_3 \sin \theta_3 \\
    r_2 \cos \theta_2 - r_3 \cos \theta_3 & -r_1 \omega_1 \cos \theta_1
\end{bmatrix}
\begin{bmatrix}
    \omega_2 \\
    \omega_3
\end{bmatrix} =
\begin{bmatrix}
    r_1 \omega_1 \sin \theta_1 \\
    -r_1 \omega_1 \cos \theta_1
\end{bmatrix}
\]

4. Matrix equations of angular acceleration:

\[
\begin{bmatrix}
    -r_2 \sin \theta_2 & r_3 \sin \theta_3 \\
    r_2 \cos \theta_2 - r_3 \cos \theta_3 & -r_1 \omega_1 \cos \theta_1
\end{bmatrix}
\begin{bmatrix}
    \alpha_2 \\
    \alpha_3
\end{bmatrix} =
\begin{bmatrix}
    r_1 \omega_1^2 \sin \theta_1 + r_2 \omega_2 \cos \theta_2 - r_3 \omega_3 \cos \theta_3 \\
    -r_1 \omega_1 \omega_3 - r_2 \omega_2 \sin \theta_2 - r_3 \omega_3 \sin \theta_3
\end{bmatrix}
\]

Kinematic Results of Leg Bending Structure

The kinematic equations belong to nonlinear transcendental equations, it is difficult to get the analytic solution but instead relatively easy to get the numerical solution based on Newton - Simpson algorithm [5]. The graphs of numerical solution can be drawn as figure 7 on the platform of MATLAB software.

The kinematic results of leg bending mechanism show that the angle of lower bed plank changes from initial angle as $120.7^\circ$ to ultimate position as $179.8^\circ$ near to be horizon and the whole change angle of Y-axis is $\theta_3 = 59.1^\circ$ quite close to designed angle as $60^\circ$, while that of pedal plate rid is $\theta_2 = 29.2^\circ$ quite close to $30^\circ$ measured on
the three dimensional virtual prototype and the change of driven angle as that of X-axis is $\theta_1 = 51^\circ$. Therefore, the design and equations’ solution are right and more that the kinematic curves reflect the fluctuation and change tendency of velocity and acceleration. Moreover, there is no sharp changing point on curves, showing that the position transformation movement is smooth and steady.

![Figure 6. Kinematic analysis results of leg bending mechanism.](image)

![Figure 7. Diagram of rehabilitation bed’s position transformation.](image)

**DIAGRAMS OF DIFFERENT POSITIONS CONVERSION**

With the related functional components moving independently or in a coordinated step, the different position transformations among sitting, lying and standing can be achieved, powered by electric cylinders. The diagram of position transformation is as shown in figure 7.

**CONCLUSIONS**

With the increasing demand for modern rehabilitation nursing service and the existing bed with defects, a new rehabilitation bed system is put forward. The principle of designed scheme, main structure components and control system are
simply described, then the kinematic equations of leg bending mechanism are established and solved to evaluate the safety and stability based on some kinematic curves drawn by MATLAB software. The new design can provide a referable solution scheme for the nursing problem of the patients and olds unable to live on their own.

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