Novel 3-DOF Parallel Mechanism for Bedridden Repositioning System: A Kinematics Analysis

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***Abstract*—The contribution of this paper is two folds – it reviewed current design of bedridden repositioning systems based on parallel mechanism and proposed a novel 3-DOF mechanism based on 2-RPS 1-PRS mechanisms. The methodology adopted to identify the mechanism is based on systematic design process, including functional analysis and benchmarking of all available bedridden repositioning systems, using Pugh's method. In order to verify the validity of the proposed mechanism, its inverse kinematic characteristics are critically analyzed. The analytic formulae are derived for inverted displacement and then modeled using MATLAB program. The result is verified to be consistent with the calculated ones.**

***Index Terms*—pressure ulcer, medical bed, bedridden, parallel kinematics mechanism**

I. Introduction

Recently, the medical bed rehabilitation (MBR) devices using robotic technology receive much attention from researchers due to its growing potential in assisting medical nurse or caregiver and help to prevent a number of diseases among bedridden (pressure ulcers, pneumonia etc.). Additionally, successful implementation of MBR could also reduce the incident of anguish back pain among help care personnel at home or hospital as the task of repositioning bedridden are done manually every 2 to 4 hours. Typical functions of bed reposition include Trendelenburg motion, Fowler's motion and adjustable height of structure bed. The medical bed structure consisted of two frame mechanism: one is upper frame, and another is the lower frame. There are a large number of designs upper frames with using Fowler's function, and also lower frame using adjustable height and Trendelenburg motion. However, the posture change by turn of human body position for the rest of function in one medical bed mechanism is still a challenge. Among these structures of bed, the advantages of parallel kinematics mechanism (PKM) as a lower frame can perform Fowler, Trendelenburg and adjustable height in one design. The use of mechanism bed in order to reposition patient as practical was limited due to complexity of design for turning frames with human body and many factor need to consider for application, hence very limited number of reports. EPOSbed is provided an artificial intelligent with lateral position and Fowler's movement at upper frame and Trendelenburg motion with adjustable height of bed at lower frame. Nevertheless, the design is complicated due to structure of bed using a nine actuator [1]. The modification of parallel mechanism as a lower frame will be simplicity the design of bed and increase the function. It's having advantages in terms of high load carrying capacity, accuracy and lower cost manufacturing. The structure of PKM with a moving platform that connected to fix based by linkage can be applied in the medical field, driving simulator and so on. Jody et al [2] reported that PKM with 2-DOF ankle rehabilitation is an ability to carry all function exercise's protocol as required.

This paper is organized as follows. Firstly, the description of a human body lied on bed and its effect. Next, the types of clinically for rehabilitation of bedridden patients are examined. This leads to the study the current devices for medical bed and characterization of available devices. The Pugh concept selection is applied to recognize the potential devices for develop. The result of new mechanism 3-DOF of the lower frames is presented. Further kinematics analysis of the 3 DOF of 2-RPS 1-PRS mechanism a performed and numerical verification with position is conducted using a program prepared in MATLAB and lastly, conclusions make up for this research.

II. Human Body Lied on Bed

The bedridden people body at supine position will have discomfort and anguish conditions due to long lying under the bed. This situation happens because the weight of organs, muscles and bones are pulled by gravity will reduce function of the human body to be optimal. These phenomena will affect the health condition of people, especially those who are great to reduce mobility. One of the diseases with causes of pressure ulcer (PU) is the incidence of high forces from part of the human body to a large skin. The flow of blood circulation will slow, and then it's allowing a PU to develop. Others disease cause by laying down at bed is pneumonia. These situations happen because of the bedridden people are not taken a deep breath in. This causes the infection to the one or both lungs by viral pneumonia due to the perfect environment with under ventilated areas. In medical, reposition of the human body every 2 to 4 hours is one of the techniques to prevent the PU. This process is done by two or three nurse rotated along the x-direction (α angle)

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as shown in Fig. 1. The tilt position of this method is 90 degrees with turn right or turn left body of bedridden people. Besides that, the Trendelenburg movement is human body rotated along the y-direction (ϕ Angle) by 15 to 30 degrees with feet higher than the head as shown in Fig. 1. The reverse Trendelenburg position is opposite direction of tilted Trendelenburg of the human body. This activity will help to improved blood circulation among bedridden people. Other clinically approached is Fowler's movement, where one type of rehabilitation for disabled people by doing a sitting position with a leg and foot movement. This activity will give relaxing of tension abdominal muscles and allowing for improved breathing among people at supine position. The sitting position with tilt angle is 45 to 60 degrees will help to improve their comfort during watching television or other activities.

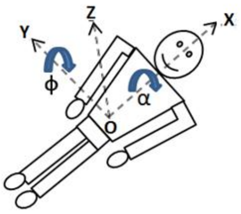


Figure 1. Illustration of a human body at supine position.

A. Functional Analysis of the Medical Bed Rehabilitations

Nowadays, there are several types of medical bed based on function and requirement from the patient at a hospital. The relationship of function and current devices is as shown in Table 1. The application of Pugh's concept selection is used for improve the concept of design [3]. The strength and weakness of each device are identified by comparison with a reference's concept. The concept of design by Valdemoros Tobia.O *et al*. 2011 is selected for references. The relative performances of “better than” (+), “same as” (0), or “worse than” (-) is placed in each cell on the table to represent a result of comparisons with references that related to the criteria. With functionality analysis of devices, seen that the Trendelenburg motion and Fowler's motion and adjustable height is almost applied in medical bed structure. However, reposition of movement is difficult part to combine with other's structure, and this gives open problem to apply in this rehabilitation medical bed. The design by [4] is one of the type devices that can apply reposition method but not the rest of function. Based on Table I, the first rank MBR is design by Pavlović. N. *et al*. 2010 design and it is selected for further improvement. The result shows that the design is worse than others in terms of lateral tilt angle with less 45 degrees and sliding condition due too flat at top surfaces. The proposal to increase the performance of this device is a modification at lower frame with using parallel mechanism as described in [5] to get a tilt angle more than 45 degrees. By increasing the tilt angle will help to prevent back pains among healthcare personnel [6]. This part of devices will cover in next section.

B. Reposition Human Body and Corresponding Medical Bed based on Parallel Mechanism

Based on Table I, the selected of design by Pavlović. N. et al.2010 is done because this rehabilitation device has potentials to fulfill the current function requirement with some modifications. The lower frames of these devices have a moving platform, a base and three PS (prismatic-spherical) legs are illustrated in Fig. 2(a). A new lower frame mechanism with two RPS (revolute-prismatic-spherical) legs and one RS (revolute-spherical) leg as describe on [7] would solve the lateral tilt. However, to get a function of adjustable height, the design of one RS leg can be replacing with one PRS (prismatic-revolute- -spherical) leg as shown in Fig. 2 (b). Consider two rotations of reposition human body and represent these on three axes as in Fig. 1 where α angle represents turning left or right human body in Fig. 1 and the ϕ angle represent Trendelenburg movement.

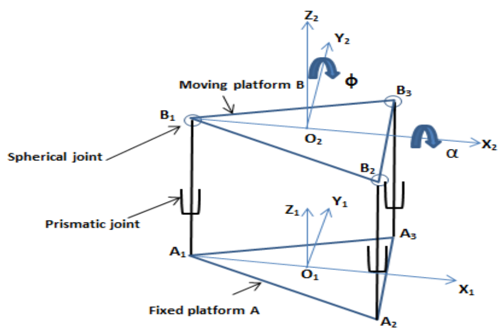
TABLE I. PUGH CONCEPT SELECTION

Criteria	Developer [8] 2011	[9] 2010	[10] 1994	[11] 1992	[12] 1977
Lateral Position	0	-	-	-	-
Fowler motion	0	0	0	-	0
Trendelenburg	0	0	0	0	0
Adjustable height	0	0	0	0	0
Easy to manufacture	-	+	+	+	+
Low cost	-	+	+	+	+
Payload	-	+	-	-	-
Sum “+”	0	3	2	2	2
Sum “0”	4	3	3	3	3
Sum “-”	3	1	1	2	2
Net Sum	-3	2	1	0	0
Rank	4	1	2	3	3

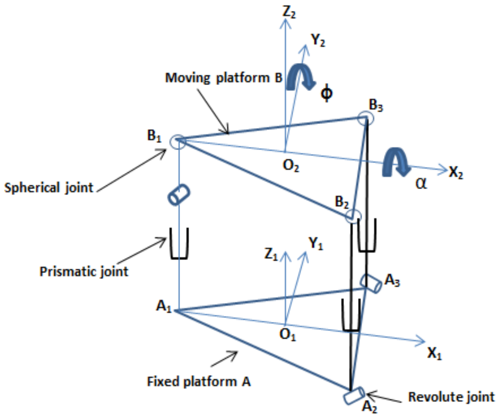
III. KINEMATICS ANALYSIS OF THE 3-DOF OF 2-RPS 1-PRS PARALLEL MECHANISM

The structural innovations of 3-DOF 2-RPS 1-PRS mechanism are consisted the top moving platform B, a fixed base platform A, one PRS leg with linear actuator connecting to base platform and two RPS legs with actuator for each leg is illustrated in Fig. 2 (b). By using Grubler’s formulas, the DOF of the novel mechanism can be identified. Hence, the platform has three DOF, which can be verified with this equation as

$$F = \lambda(n-j-1)+\sum_i f_i \;=6\;8-9-1\;+\;15=3 \quad (1)$$



(a)



(b)

Figure 2. Illustration of parallel kinematics mechanism for (a) 3 PS and (b) 2-RPS 1-PRS

Develop an Inverse Kinematics of 2-RPS design. The location of moving platform can be defined by using homogeneous transformation matrix 4x4 with mapping the position vector from one coordinate system into another. Homogenous transformation matrix for this system with α is an angle rotation of roll attitude and is ϕ is an angle rotation of pitch attitude as given:

And for homogenous coordinate for mobile platform B_i in the coordinator system $OX_2Y_2Z_2$ are given:

$$T = \begin{bmatrix} \cos\phi & \sin\phi\sin\alpha & \sin\phi\cos\alpha & 0 \\ 0 & \cos\alpha & -\sin\alpha & 0 \\ -\sin\phi & \cos\phi\sin\alpha & \cos\phi\cos\alpha & a+z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$B_1 = \begin{bmatrix} X_{B1} & Y_{B1} & Z_{B1} & 1 \end{bmatrix}^T = \begin{bmatrix} -r & 0 & 0 & 1 \end{bmatrix}^T$$
$$B_2 = \begin{bmatrix} X_{B2} & Y_{B2} & Z_{B2} & 1 \end{bmatrix}^T = \begin{bmatrix} \sqrt{r^2 - b^2/4} & -b/2 & 0 & 1 \end{bmatrix}^T \quad (3)$$
$$B_3 = \begin{bmatrix} X_{B3} & Y_{B3} & Z_{B3} & 1 \end{bmatrix}^T = \begin{bmatrix} \sqrt{r^2 - b^2/4} & b/2 & 0 & 1 \end{bmatrix}^T$$

The transformed coordinates P_i after mobile platform B_i move to other position are shown as the following solution:

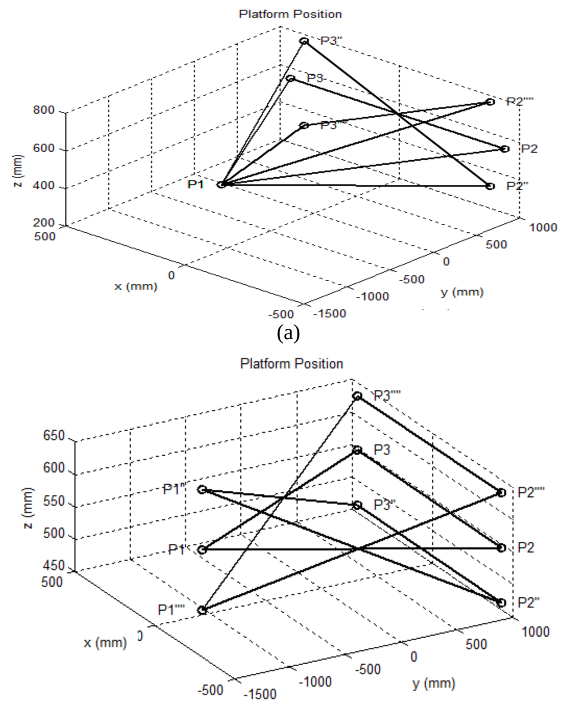
$$P = T \;\; X \;\; B \quad (4)$$

For solving the inverse kinematics problems of the novel 3 DOF parallel robots, the analytical expressions for the actuator length S_i can be established:

$$S_i = |P_i - B_i| \quad (5)$$

A. Numerical Verification of Kinematics and Position

Numerical example was developing to solve the inverse kinematics of the innovations of 2-RPS-1PRS as shown in Fig. 2 using MATLAB software. The parameters of the parallel robot are b = 900 mm and r = 1075 mm. These examples are choices to verify the eq. (2) to eq. (5) for identified positions of moving platform. Based on adjustable of height of medical bed, the initial state for vertical distance between top platform and based platforms as a = 470 mm. Next, the extension of the vertical distance as the input parameter is z = 100 mm. The initial state of rotational angle of moving platforms was assumed as $\alpha = 0^0$ and $\phi = 0^0$. The relationship of each leg length robot for each of movements and position's platform was identified in the following analysis: (1) Analysis of roll attitude**,** Fig. 3(a) shows the moving platform position with various angles of rotation along the x-direction. (2) Analysis of pitch attitude**,** Fig. 3 (b) shows the moving platform position with various angles of rotation along the y-direction. The examples of moving platform position for these parallel robots are consisting of three types of angle of rotation. The result from the leg's distance for each mobile platform with various positions calculated by the program is shown in Table II.



(a)

(b)

Figure 3. Illustration of platform position for (a) roll attitude and (b) pitch attitude

TABLE II. LEGS LENGTH FOR VARIOUS PLATFORM POSITIONS

	Platform Position	Legs Length (mm)		
		S_1	S_2	S_3
Row Attitude	Idle ($\alpha = 0^0$ and $\phi = 0^0$) P1P2P3	570	570	570
	Angle rotation ($\alpha = 30^0$ and $\phi = 0^0$) P1P2P3"	570	350.2	797.2
	Angle rotation ($\alpha =-30^0$ and $\phi = 0^0$) P1P2""P3""	570	797.2	350.2
Pitch Attitude	Idle ($\alpha = 0^0$ and $\phi = 0^0$),P1P2P3	570	570	570
	Angle rotation ($\alpha = 0^0$ and $\phi = 5^0$) P1"P2"P3"	663.7	484.9	484.9
	Angel rotation($\alpha = 0^0$ and $\phi = -5^0$) P1""P2""P3""	476.3	655.1	655.1

B. Conclusion

A new rehabilitation of medical bed with using 3 DOF 2-RPS 1-PRS parallel mechanisms that can fulfill all functions have been successfully identified by using Pugh's concept selection. By using MATLAB software, the inverse kinematics model of the motion platform can be verified. The results were very similar, and this type of parallel mechanism is selected to fulfill the design of a requirement for medical bed. These results could also provide an insight to our future work to analyze its workspace and singularity.

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