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Multi - mechanism Coalescence Design and Matrix Expression of Logic Action Sequences of the Over-turn Nursing Robot Part I: Functions and Coalescence Design

Multi - mechanism Coalescence Design and Matrix Expression of Logic Action Sequences of the Over-turn Nursing Robot
Part I: Functions and Coalescence Design

Lizhi Gu[1,2], Shanping Gao[1], Chunyang Gu[3], Yuantang Huang[3], Feiyue Xu[3], Xiang Zhong[3], Kai Chen[3] and Jinling Song[1,4,*]

[1]Key Laboratory of Virtual Manufacturing Technology of Fujian Universities, Quanzhou University of Information Engineering, No. 249, Bodong Road, Fengze District, Quanzhou, Fujian, China. 362000
[2]College of Mechanical Engineering and Automation, Huaqiao University, No.668, Jimei Boulevard, Jimei District, Xiamen, China. 361021
[3]The University of Nottingham Ningbo China, IAMET-229, Sir David and Lady Susan Greenaway Building, 199 Taikang East Road, Ningbo, China. 315100
[4]Quanzhou Normal University, No.398, Donghai Boulevard, Quanzhou, Fujian, China. 362000

*Corresponding author

Abstract. In order to effectively solve the problem in over-turn of a bedridden person with the assistance of external force, a double bed face- three embedded leave over-turn nursing robot with the flexible compensation was put forward, with the abstraction of the bedridden person as an organism. This robot, on the basis of concept gesture of the person in bed and the state of the robot supporting and proving the gesture with the actions and combination of the two bed faces, held the complete function of over-turn nursing with 7 states corresponding to 5 gestures of the bedridden person obeying the fundamental requirements of safety, rapidity, and comport. The design method of "PS-MM-KD" was proposed for multi-mechanism coalescent system with related specific tasks induced from the original problems with Systems Engineering. Mechanics and Mechanisms, then applied in the concrete sub-system design followed by analysis and verification of both the scheme and the sub-systems in the design, using the Kinematics and Dynamics, implementing the gears, chain wheel, slewing mechanism, screw nut and mortise and tenon joint type clutch mechanism design successfully. Based on those above, a "two-bed face/three-leaf embedded flexible compensation nursing robot" was designed adopting to all ages, people of various kinds of body geometry. PLC, sensor and logic algorithm were used to carry out the control and operation of 7 state-5 posture sequences for realization of the automation and intelligent over-turning in safety, comfort, and convenience.

1. Introduction
Over-turning nursing robot can provide assistance services such as side lying and over-turning, especially for people who encounter difficulties or obstacles when turning over in bed, which is of great significance for (1) patients including those who are admitted for examination, recuperation during operation and operation, and who cannot or should not turn over themselves for a period of time; (2) a person who is unable to take care of himself or is completely disabled; and (3) the wounded

who is unable turn over by himself or herself. Currently, there are bed-chair conversion products and back-lifting nursing beds, etc., but nursing beds (robots) that can make bedridden people turn over automatically have high functional performance requirements, complex structure, and require multiple mechanisms with intelligent control, which are reported few and far in between.

Fortunately, some advances on this field have been gained，though not good enough. Ishac, Karlos at al. [1] raised a gesture based robotic arm control for meal time care using a wearable sensory jacket. Demmer, Julia at al. [2] improved a retrospective analysis method for a HMM based gesture recognition system in a functionalized nursing bed. Wang, Shigang at al. [3] designed and manufactured a kind of multi-function electric nursing bed based on ergonomics with top-down method to complete the design of nursing bed control system. Landau, Thomas P. at al. [4] permitted considerable flexibility in the assignment of nurses (as well as patients) to individual units with statistical techniques. Ktistakis, Iosif Papadakis at al. [5] presented a new multi-modal Human-Machine Interaction (HMI) scheme-model for the co-operation of a robotic-nurse (here a robotic wheelchair) and its human user recognizing (i) a set of voice commands, (ii) a set of body gestures and poses and (iii) the appropriate body angles associated to skeletal data obtained through a set of cameras. Jiang, Jingang at al.[6] raised and predicted the informatization and robotization of elderly nursing will become the necessary development trend in the future. Chen, Diansheng at al. [7] created an off-bed detection and bathroom accident monitor system for nursing home. Balistreri, Maurizio at al [8] used care robots to train nursing staff with the tools of care to training opportunities and moral considerations. Ahn, Ho Seok at al. [9] proposed robotic health care service system to serve multiple patients with multiple robots, for a health care environment, especially for a family doctor practice. Cremer, Sven at al. [10] reported on analysis toward identifying design requirements for an Adaptive Robotic Nursing Assistant focusing on application requirements, envisioned as a mobile assistive robot that can navigate hospital environments to perform chores in roles. Yu, Hongjiang at al. [11] put forward a nursing robot safety path planning based on improved star algorithm avoiding the head and foot collision obstacles. Tashiro, Takehiro at al.[12] carried out wearable auxiliary tool for behavior assistance of elderly who requires nursing care.

2. Basic Functional Performance Requirements and Design Consideration

2.1. Basic Requirements
For the convenience of design, the biological model is transformed into a mechanical model, and the human body is regarded as a rigid body for force analysis and mechanical calculation. The biological factors are taken into account in the actual design. Two new concepts are known for the research details later on. Posture or gesture is the situation that the user lies in bed. The state or status is the combination and position relation of the two bed faces.

(1) the four basic gestures + 360-degree omni-directional postures;

(a) gesture 1: common gesture, supine; (b)gesture 2:prone; (c)gesture 3:sidelie 1，the heart is at low position; (d)gesture 4: sidelie 2; (e)gesture 5: the person in bed with the angle from the originally horizontal   position to the current orientation, anticlockwisely. $0^{o}<\theta<360^{o}$.

(2) adopt the 6-point positioning principle and implement the complete positioning;

(3) human body as a kind of organism is supposed to fix, considering the elderly and the sensitivity of the patient's skin, and parts of the body may be selected for fix, such as the calf, shank, or the waist;

(4) five position states+ transitional states;

(a) state 1:common position state and posture, namely bed surface 1 in principal position, bed surface 2 right down, and leaf B extended; (b)state 2: when the bed surface 1 in principal position, bed surface 2 right down, and leaf B extended with leaf C upright; (c)state 3:when the bed surface 1 in principal position, bed surface 2 right down, and leaf B extended with leaf A upright; (d) state 4:bed surface 2 in principal position, and bed surface 1 right down with leaf B extended; (e) state 5:bed surface 1 or 2 in principal position, but with any angle from horizon, bed surface 2 or 1 at up, and leaf B extended. And other two transitional states added.

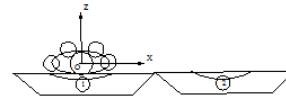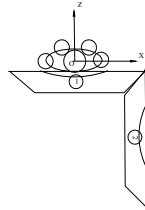*2.2. Logical Relationship between Bedridden Posture and Robot State*

Figure 1. Posture1, supine- the robot state1.   **Figure 2.** Transition state with posture1, supine.

For every gesture of the bedridden person, at least the nursing robot provides a state to match. Therefore, bedridden posture and robot state will appear at least in pairs, and the robot state can be accompanied according to optimization in the design.

3. Multi-mechanism Coalescence Design by "PS-MM-KD" Method with Aim of Safety, Swiftness and Ease

3.1. Design Principles and Methods
Systems Engineering principle determines overall functional performance, and mechanics and mechanism principles for the concrete designs. Kinematics and Dynamics are applied to make verification and improvement of these designs for better solutions to the original problems. The three-stage design methods are shown in figure 3.

3.2. Functional Design
Overall function: adapt to the needs of different body types of users within a certain range, turn over safely, quickly and freely (rotate 180 °), realize the automatic left side lying (under the heart) or right side lying and restore the horizontal supine.
Flexible function: based on the body weight and body width of adult statistics, a compensation link is designed so that people with different body widths can use the bed freely.
Safety function: ensure that the bedridden person can avoid any direct or indirect injury caused by turning over.
Swift function: under the premise of ensuring safety and ease, shorten the turning time as far as possible.
Comfortable function: in the process of turning over in bed, comfortable, no dizziness, vomiting and other adverse reactions, positioning, fixation (clamping) and speed of movement should be appropriate and humanized, the body to bear as little pressure as possible (no pressure pain).
A three-leaf bed is designed, with leafs A,B and C, and these three leafs can move and control respectively and cooperate with each other to achieve the expected function.

3.3. Coalescence Design of Multi-mechanisms

3.3.1. Research and design of flexible compensation links based on feedback control. Two special forms of flexible air bags are designed symmetrically on both sides of bed base B, and the position sensor is set at the end (adjacent to leaf A and leaf C). The distance between the side of flexible air bag and the side of the leaf is used as the adjustment signal. When the distance between leaf A and leaf C increases, the air bag is inflated to increase the width of segment B. When the distance between leaf A and leaf C decreases, the airbag deflates, reducing the width of section B. This function ensures that users with different body widths can properly use the bed. Within a bed, three leafs were combined with airbag and sensor, implementing significant functions and specific performance.
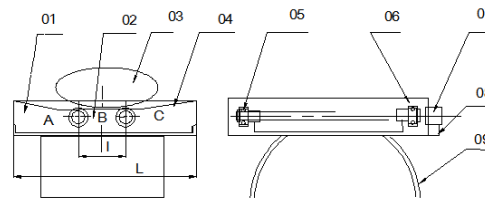
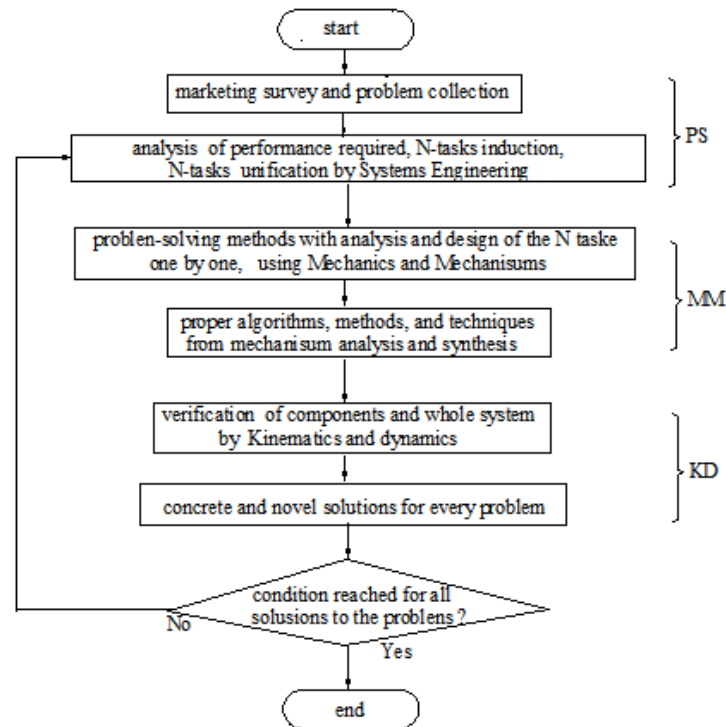**Figure 3.** The three-stage design with PS-MM-KD methods.

Figure 4. System composition and structural functions.

3.3.2. The opening and closing nut with other mechanisms. When the two beds are in positions for rotation together the two half central shafts are put into operation, with the opening and closing nut. The combination of the opening and closing nut and the screw nut mechanism with the gear mechanism, realizing clutch - rotation change and rotary movement, see figure 7.

3.3.3. Bed surface connection hinge. This hinge functions a shaft, for the two beds to come together to rotate, providing sequences of states of the nursing robot. On the hinge a sprocket is mounted and driven by a chain moving from the main motor. Integration of bed surface connection hinge with rotary mechanism and sprocket mechanism provides the nursing robot with all the beds movements corresponding to the requirement of the postures of the bedridden person. From above, the whole system has been obtained with "PS-MM-KD" (refers to Performance and Systems engineering; Mechanics and Mechanisms engineering; Kinematics and dynamics) design method, see figure 8.
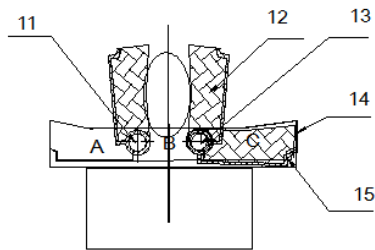
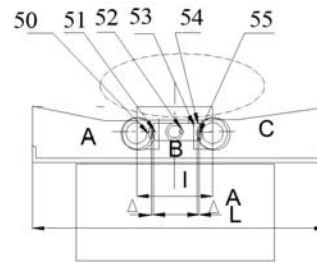**Figure 5.** Sidelie and intermediate process**.**   **Figure 6.** Airbag compensation device.

This hinge functions a shaft, for the two beds to come together to rotate, providing sequences of states of the nursing robot. On the hinge a sprocket is mounted and driven by a chain moving from the main motor. Integration of bed surface connection hinge with rotary mechanism and sprocket mechanism provides the nursing robot with all the beds movements corresponding to the requirement of the postures of the bedridden person. From above, the whole system has been obtained with "PS-MM-KD" design method, see figure 8, to find out the way from the current posture to the target one.
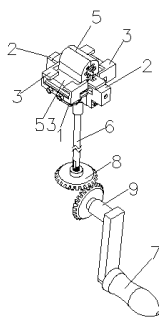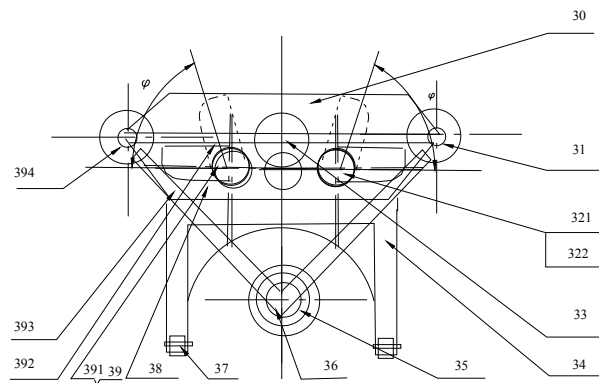

Figure 7. The opening and closing nut.   **Figure 8.** Nursing robot with coalescence of several mechanisms.

4. Conclusions
The movement of over-turning of human body organism has been abstracted in bed, and the basic functional requirements of the nursing robot for over -turning were summarized — supine, sidelie 1, sidelie 2, prone and arbitrary posture with safety, rapidity，and comfort.

A so-called "PS - MM - KD" design method has been put forward to achieve multi-functions with complex systems of the mechanisms. From the overall requirements, systematic solution to the problems was put forward by the Principle of Systems Engineering. Using Mechanics and Mechanisms, analysis and synthesis were done on the comprehensively specific mechanisms, followed by Kinematics and Dynamics, realizing coalescence of the gear mechanism, slewing mechanism, lead screw nut device, and the mortise and tenon joint type clutch for the 5 postures of the bedridden person - 7 states of the robotic system with guarantee.

A two-bed face/three-leaf embedded flexible compensation nursing robot was proposed and designed with wide flexible compensation link of airbag, adopting to all ages, people of various kinds of body geometry. PLC, sensor and logic algorithms were used to complete the control and operation of 7 state-5 posture sequences, to realize the automation and intelligent turning safely, comfortably, conveniently and reliably.

References

[1]   Ishac, Karlos; Suzuki, Kenji. *Gesture based robotic arm control for meal time care using a wearable sensory jacket,* Proceedings of 2016 IEEE 4th Int. Symposium on Robotics and Intelligent Sensors: Empowering Robots with Smart Sensors. p122-127, December 17 - 20, 2016, Tokyo, Japan

[2]   Demmer, Julia; Kitzig, Andreas Naroska, Edwin. *Improvements of a retrospective analysis method for a HMM based gesture recognition system in a functionalized nursing bed.* Proceedings of 2017 IEEE /SICE Int. Symposium on System Integration, p487-492,December 11-14, 2017, Taipei, Taiwan

[3]   Wang, Shigang; Shi, Wei; Liang, Yinghuai; Huang, Longjun; Huang, Zhanqiang.*Design and manufacture of multi-function electric nursing bed*. Journal of Physics: Conference Series,Vol. 1213 (5) 2019, Int. Conf. on Advanced Algorithms and Control Engineering, ICAACE 2019 - Electronics Engineering and Process Control. April 26- 28, 2019. Guilin, China

[4]   Landau, Thomas P.; Thiagarajan, T.R; Ledley, Robert S. *Cost containment in the concentrated care center: A study of nursing bed and patient assignment policies.* Computers in Biology and Medicine, p205-238,vol. 13 (3),1983

[5]   Ktistakis, Iosif Papadakis; Bourbakis, Nikolaos. *A multimodal human-machine interaction scheme for an intelligent robotic nurse.* Proceedings of Int. Conf. on Tools with Artificial Intelligence, ICTAI, p749-756, November 5-7, 2018，Volos, Greece

[6]   Jiang, Jingang; Huang, Zhiyuan; Huo, Biao; Zhang, Yongde; Song, Shichang. *Research progress and prospect of nursing robot.. Recent Patents on Mechanical Engineering.* vol. 11 (1) 2018, p41-57

[7]   Chen, Diansheng; Zeng, Binglin; Sun, Zhen; Zhao, Linshan; Huang, Zheng; Wang, Min. *An off-bed detection and bathroom accident monitor system for nursing home.* Proceedings of 2016 Int. Conf. on Advanced Robotics and Mechatronics, ICARM 2016. p53-58, August 18-20, 2016, Macau, China

[8]   Balistreri, Maurizio; Casile, Francesco. *Care Robots: From Tools of Care to Training Opportunities.* Moral Considerations. Vol. 1008, Advances in Intelligent Systems and Computing. P18-25, Proceedings of 9th Int. Conf. in Methodologies and Intelligent Systems for Technology Enhanced Learning, MIS4TEL 2019. June 26-28, 2019, Ávila, Spain

[9]   Ahn, Ho Seok; Zhang, Sheng; Lee, Min Ho; Lim, Jong Yoon; MacDonald, Bruce A. *Robotic health care service system to serve multiple patients with multiple robots.* Proceedings of 10th Int. Conf. on Social Robotics, ICSR 2018, p493-502, November 28-30, 2018, Qingdao, China

[10]   Cremer, Sven; Doelling, Kris; Lundberg, Cody L; McNair, Mike; Shin, Jeongsik; Popa, Dan. *Application requirements for Robotic Nursing Assistants in hospital environments,* Proceedings of SPIE   The Int. Society for Optical Engineering 3rd Sensors for next Generation Robotics Conference, April 20 - 21, 2016, Baltimore, MD, United States

[11]   Yu, Hongjiang; Miao, Xingang; Wang, Su; Hu, Yawei. *Nursing robot safety path planning based on improved a star algorithm.*Journal of Computers ,p282-289,vol.30 (3), 2019

[12]   Tashiro, Takehiro; Aoki, Kanta; Lee, Yongkwun; Sakaki,Taisuke. *Research and development of wearable auxiliary tool for behavior assistance of elderly who requires nursing care.* Proceedings of ICCAS 2017, 2017 17th Int. Conf. on Control, Automation and Systems p1501-1504,October 18- 21, 2017, Jeju, Republic of Korea