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

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Part I: Functions and Coalescence Design

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 to 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: side lie 1, the heart is at low
position; (d)gesture 4: side lie 2; (e)gesture 5: the person in bed with the angle from the originally
horizontal position to the current orientation, anticlockwisely. $0^\circ < \theta < 360^\circ$.
(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.](image)

![Figure 2. Transition state with posture1, supine.](image)

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 leaves 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.
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.
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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, sidelicie 1, sidelicie 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.
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