IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: Lizhi Gu *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **790** 012155

IOP Conf. Series: Materials Science and Engineering **790** (2020) 012155 doi:10.1088/1757-899X/790/1/012155

Multi - mechanism Coalescence Design and Matrix Expression of Logic Action Sequences of the Over-turn Nursing Robot
Part II: Gesture-state in Sets and Matrix

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. As is expressed in Part I, Functions and coalescence design of the over-turn nursing robot, the performance and requirements have been put forward with systematic design of several mechanisms. Here, in order to control and function well the over-turn nursing robot, the three-dimensional and five-dimensional Euclidean space with the real number were adopted in terms of sets for gesture of the bedridden person and the corresponding state of the robot, respectively. The matrix method was employed to define and describe the gestures-robot performance and its transition path. The gesture-state sequence matrix not only accurately and clearly expressed the gesture series, state sequence and their corresponding relations, but also laid a theoretical and technical foundation for the path planning from the current gesture to the target one. The control and operation of 7 states and 5 gestures were done to realize the automation and intelligent over-turning safely, comfortably and conveniently.

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. In order to plan the logical sequential movement of the robot, the gesture - state and its transition path are supposed to define and describe by using mathematics. 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, especially for the gesture of bedridden people and the corresponding state of the robot with mathematical expressions.
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] used the 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 based on the theory of stochastic processes. Richert, Anja, at al. [5] used the humanoid robot pepper and extend its software functions so that it can take initiatives in man-machine-conversation. Bae, Gang-Tae at al. [6] put forward an omni-directional power-assist-modular (PAM) mobile robot for total nursing service system, focusing on verifying a kinematic model of dual-offset active wheel casters. Sheba, Jaichandar Kulandaidaasan at al. [7] investigated the effect of elderly interacting with pet robot through multimodal peripheral devices with a different level of cognitive challenges using questionnaire, facial temperature, EMG and EEG. Yu, Hongjiang at al. [8] depicted a nursing robot safety path planning based on improved a star algorithm avoiding the head and foot collision obstacles. Lin, Chingszu at al. [9] developed and waist joint on the prototype robot and also the control system in order to emulate quadriplegic and hemiplegic patients' tendency to fall over. Zheng, Wenlei at al.[10] researched on path planning of family nursing robot based on robot operating system for solution to the problem of indoor navigation of family nursing robot.

The current study will propose a sequence matrix for the gesture series, state sequence and their corresponding relations, to realize the automation and intelligent over-turning in safety, comfort and convenience.

2. Gesture and State Expression by Sets in Multi-dimensional Euclidean Space with Real Number

A sequence of objects may be expressed in terms of sets. Gesture of the person in bed with several statuses may have the form of

$$\{\text{gesture}(i,j,\dots,n)\},\ i=1,2,\dots,I;\quad j=1,2,\dots,J;\ \dots;\ n=1,2,\dots,N \tag{1}$$

It is meant that the sequence of the gesture of bedridden person may hold several details to tell difference among these gestures, and the different details may be depicted with different coordinates. Therefore, the gesture of bedridden person can be defined and indicated by sets with the multi-dimensional euclidean space with real number. Similarly, the state of the over-turn nursing robot may be expressed in terms of

$$\{\text{state}(u,v,\dots,z)\},\ u=1,2,\dots,U;\quad v=1,2,\dots,V;\ \dots;\ z=1,2,\dots,Z \tag{2}$$

The number of dimension of the gesture or state may be chosen according to the intention and extent to depict.

3. Matrix Expression of Gesture of the Person - state of the Robot and Transition

3.1. Gesture - state Definition in Set and Mathematical Expression in Vector

Gesture is the situation of the user lying in bed, which can be expressed by set and sequence, as it has been mentioned in section 3.The state is the combination and position relation of the two bed faces.

By set, in the nursing situations, gesture can be expressed as

$$\{\textbf{gesture}\ (\boldsymbol{I})\}=\{\textbf{ges1}\ (\boldsymbol{i}),\ \textbf{ges2}\ (\boldsymbol{j}),\ \textbf{angle}\ (\boldsymbol{\theta})\} \tag{3}$$

Where, ges1(i)shows the gesture of supine or prone, i=0,1,2;

ges(j)indicates the side lie of the person, j=0,1,2;

angle(θ)presents any gesture and orientation of the person, θ is the angle from the originally horizontal position to the current orientation, anticlockwisely $0^o<\theta<360^o$.

And state can be expressed in terms of

$$\{\text{state}(i,j,n,p,m)\}=\{\text{state1}(i),\ \text{state2}(j),\ \text{state3}(n),\ \text{state4}(p),\ \text{state5}(m)\} \tag{4}$$

IOP Conf. Series: Materials Science and Engineering **790** (2020) 012155 doi:10.1088/1757-899X/790/1/012155

$$\{\text{state}(i, j, n, p, m)\} = \{\mathbf{bsf1}(\boldsymbol{i}),\mathbf{bsf2}(\boldsymbol{j}), \text{If A}(\boldsymbol{n}), \text{If B}(\boldsymbol{p}), \text{If C}(\boldsymbol{m})\} \quad (5)$$

3.2. Analysis and Design of Gesture - state - logic Action Process

The movement process of over-turning in bed depends on the form of assistance system. But the gesture requirement of the bedridden person is clear and random, and the motion guarantee provided by the corresponding robot system is optional. Through analysis, there are 5 kinds of condensed gestures and 7 kinds of corresponding states, as shown in table 1. with respect to the sequential logic actions of the coalescence of multi-mechanisms.

4. Matrix Expression of Logical Relation Sequence and Transition Corresponding to Bedridden Gesture

4.1. Any Gesture-state Relation Sequence in Matrix

The matrix is introduced to express the corresponding logic relation between the gesture of the bedridden person -robot state, making the further expression and elaboration of the complex problems even succinctly, see figure 1. If the gesture of the bedridden person - the state of the over- turn nursing robot is defined according to equations (3), (4) and (5) and the corresponding relationship sequence is written in matrix form, then the robot state corresponding to the four gestures of the bedridden person is written on the position of the main element, as shown in figure 8.The bedridden person can take any kind of gesture and the supporting state that the robot should provide can be obtained immediately.

In order to better highlight the relationship between the gesture of the bedridden person and the state of the over-turn nursing robot, especially to express the transition of the state of the nursing robot from the current gesture to the target gesture, the expression of the state can be further simplified to highlight the main problems and safe the space occupied. Take the simplified expression for granted.

4.2. Gesture-state Relation Sequence in Matrix and the Current -target Path Panning

Give values to equations(4)and(5), respectively, then the concrete expressions may be obtained for the gesture and the state. The gesture of the bedridden person is taken as the column and column identification, and the robot state corresponding to the gesture of the bedridden person is taken as the main element value (frame, to show the difference), and the transition state (intermediate process) is the non-main element value, forming the state matrix of five kinds of gesture, as shown in figure 2.

In this way, not only the matrix shown in figure 1 can be simplified, but also the supporting state corresponding to a gesture transition and its transformation, namely the current state and the target state path, can be expressed.

4.3. Application Example

Matrix application example 1

From normal state to sidelie 1: g{1,0,0}→g{0,1,- (81-90)}

The corresponding initial state and target state are respectively

S{1,4,1,2,1 }, S{1 ,4,1,2,2}.

You can go in a transitional state

S{1,4,2,2,2 }.

Equation(3) may be simplified as **g{*I*,*j*,*θ*}** and equation(5) as **s{I,j,n,p,m}**

Matrix application example 2

Similarly, from sidelie 2: S{4,1,2,2,1} (let principal position be bed surface 2) to sidelie 1: S {4,1,1, 2,2}, can go through the transition state

S { 4,1,2,2,2}.

The planning of multiple paths to achieve the target state will be discussed in other article.

Table 1. Gesture- state - logical action of the robot system with mechanisms

Order	Function	State	Gesture	Logic action	Mathematic expression (result)
1	Common state	1: bed 1 center-bed2 right down; the leafs A C original B expansion	1: supine	-	**{ges1(1), ges2 (0), angle (0)}; {bsf1(1),bsf2(4), lf A (1), lf B (2), lf C(1)}**
2	Sidelie 1-1	6: bed 1 center; bed 2 right down; leaf A original B expande, C (2)	2: sidelie1	Leaf C turns anticlockwise	**{ges1(0), ges2 (1), angle (-(81-90))}; {bsf1(1),bsf2(4), lf A (1), lf B (2), lf C(2)} → (common state, optional)**
3	Sidelie 2-1	7: bed 1 center,bed 2 right down;leaves A (2), B expanded, C primitive	3: sidelie 2	Leaf C turns clockwise	**{ges1(0), ges2 (2), angle (81-90)}; {bsf1(1),bsf2(4), lf A (2), lf B (2), lf C(1)}**
4	Over-turn 1	5: bed 2 center, bed 1 right down ;leaf A,C original ;B expanded	4: prone	Bed 2 revers at 270 degs. Then it is fixedly connected with bed surface 1 and turns 180 °. Bed surface 1 turn 270 degs.	**{ges1(2), ges2 (0), angle (0)}; {bsf1(4),bsf2(1), lf A (1), lf B (2), lf C(1)}**
5	bed rotates around the central axis relative to horizon counterclock wise turn an arbitrary angle	0<θ<360	5: bedridden person at any angle from the original horizontal level, counterclock wise	One bed surface is given priority to and the other bed surface is fixed. Rotate around the central axis of the bed and stay at any angle.	**{ges1(0), ges2 (0), angle (any)}; {bsf1(1),bsf2(3), lf A (1), lf B (2), lf C(1)} or {bsf1(3), bsf2(1), lf A (1), lf B (2), lf C(1)}**
6	Over-turn 2	1: return to the common	1: supine	bed 1 reverses 270 deg.,then turns 180 ° with bed2; bed 2 turns 270 deg.	**{ges1(1), ges2 (0), angle (0)};{bsf1(1),bsf2(4), lf A (1), lf B (2), lf C(1)}**
7	Sidelie 1-2		2	Leaf C turns counterclockwise	**{ges1(0), ges2 (0), angle (-(81-90))};{bsf1(1), bsf2(4), lf A (1), lf B (2), lf C(2)}**
8	Sidelie 2-2		3	Leaf A turns clockwise	**{ges1(0), ges2 (0), angle (81-90)}; {bsf1(4), bsf2(1), lf A (2), lf B (2), lf C(1)}**

Note: when bed face 2 is in the principal position, the conditions of the two side lies are similar to that of bed face 1 when it is in the principal position.

Figure 1. Expression of robot state-bedridden person gesture matrix.

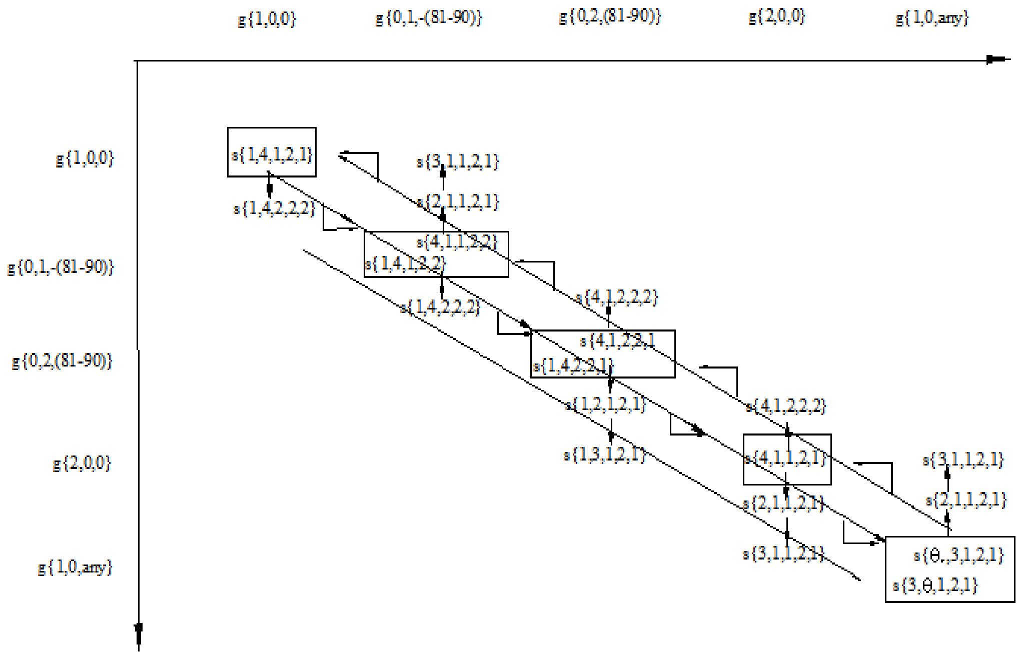

Figure 2. Gesture matrix transformation and path of the robot state - bedridden person.

5. Conclusions

The three-dimensional and five-dimensional Euclidean spaces with the real number were adopted in terms of sets for gesture of the bedridden person and the corresponding state of the robot, respectively. The gesture - state sequence matrix not only accurately and clearly expresses the gesture series, state sequences, and their corresponding relations, but also lays a theoretical and technical foundation for the path planning from the current state to the target gesture.

The control and operation of 7 states of the robot and 5 gestures of the bedridden person have been done with optimal path planning from any gesture of the bedridden person to the desired gesture, so as to realize the automation and intelligent turning of the bedridden person safely, comfortably, conveniently and reliably. Therefore, the optimal design and technological processes should be the next tasks for further study.

Acknowledgments
This research is financially sponsored by the Open Projects, Over-turn Nursing Robot (Xnzz803), and Research of Virtual Assembly Sequence Planning Based on PSO-IGA Algorithm(Xnzz1801), of Key Laboratory of Virtual Manufacturing Technology of Fujian Universities.

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