International Journal of Advanced Smart Convergence Vol.10 No.1 151-158 (2021)
http://dx.doi.org/10.7236/IJASC.2021.10.1.151

IJASC 21-1-16

The Medical Bed System for Preventing Pressure Ulcer Using the Two-Stage Control

Jungae Kim[1],Youngdae Lee[2], Minju Seon[3], *Jae-Young Lim*[4]

Assistant Prof., Dept. of Nursing, Chodang Univ., Korea[1]
Research Director, Research Center, Ninebel, Korea[2]
Research Engineer, Research Center, Ninebel Healthcare, Korea[3]
Prof. Dept. of Rehabilitation Medicine, Seoul National University Bundang Hospital, Korea[4]
jjosha6615@hanmail.net, ydlee@ninebel.co.kr, mjseon@ninebell.co.kr, drlim1@snu.ac.kr

Abstract

The main cause of ulcer is pressure, which starts to develop when the critical body pressure (32mmHg) is exceeded, and when the critical time elapses, ulcer occurs. In this study, the keyboard mechanism of the medical bed with 4 bar links was adopted, and each key can be controlled vertically. A key has one servo drive and one sensor controller which has several body pressure sensors. The sensor controllers and the servo drives are connected to the main controller by two CAN (Car Are Network) in series, respectively. By reading the maximum body pressure value of each keyboard sensor, and by calculating the error value based on the critical body pressure, the fuzzy controller moves each key so that the total error becomes zero. If the fuzzy controller fails, then it prevents ulcer by lifting and lowering the keys of the bed alternatively within a short time. Thus, the controller operates in two-stage. The validity and effectiveness of the proposed approach have been verified through experiments.

Key words: *CAN (Car Area Network), Medical bed, Fuzzy Control, Pressure Sensor, Ulcer Prevention*

1. Introduction

The main cause of ulcer is the factor: *body pressure* x *duration time*, and when it exceeds the threshold value of 32mmHg [1], ulcers begin to progress, and if the long-time elapses in this state, ulcer can occur. The frequent pressure ulcer area is shown in Figure 1. Many pneumatic ulcer prevention mattresses are also on the market, but the residual body pressure exceeds the critical body pressure of 32mmHg, so complete ulcer prevention has not been achieved yet. However, in the case of a keyboard type bed, ulcer can be theoretically prevented by moving the keyboard up and down: zero pressure by moving the keys down or adjust the duration time within a critical time when the keys are raised [2,3].

In principle, it is known that the position change time of body posture to prevent ulcer needs to be within two hours, and the shorter the better. This belongs to the duration time control of body pressure. It has been suggested that alternating key movement every 10 minutes for an automatic bed equipped with the keyboard [2][3]. This method has the advantage of not needing a body pressure sensor and closed-loop control, but it

Manuscript Received: February. 14, 2021 / Revised: February. 18, 2021 / Accepted: February. 20, 2021
Corresponding Author: jjosha6615@hanmail.net
Tel: +82-61-450-1818 , Fax: +82-61-450-1801
Assistant Prof., Dept. of Nursing, Chodang Univ., Korea

has a disadvantage that comfortability is not good when the key is lifted alternately, and the body pressure is doubled when the key is lifted.

In this study, we present two-stage control to suppress ulcer and verify the validity of the proposed approach through experiments.

2. The Developed System

2.1 Mechanical Part

Figure 1 shows the appearance of the developed bed which is mainly divided into two parts. The upper part is the keyboard consisted of *N* keys which are the modified 4 bar mechanisms and the lower one is common electric bed platform.

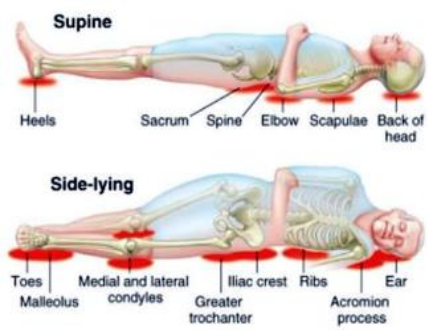


Figure 1. Areas of frequent ulcer

Figure 2 and 3 shows the 4 bar mechanism of the keyboard [2-4].

Figure 2. The appearance of the developed medical bed

Figure 3. The 4 Bar Mechanism and Its Movement

If the height h of a keyboard, with a radius r and an angle θ, can be described as follows.

$$h = r(1 - cos\theta) \tag{1}$$

$$\theta = \arccos\left(1 - \frac{h}{r}\right) \tag{2}$$

2.2 Controller Part

The main controller is divided into several parts: user interface part, motion controller one, and host interface one. And they are connected by CAN (Car Area Network) which communicates with multiple motion servo controllers and multiple sensor controllers. Sensor signal processing parts are also included. Figure 4 shows the organization of the main controller.

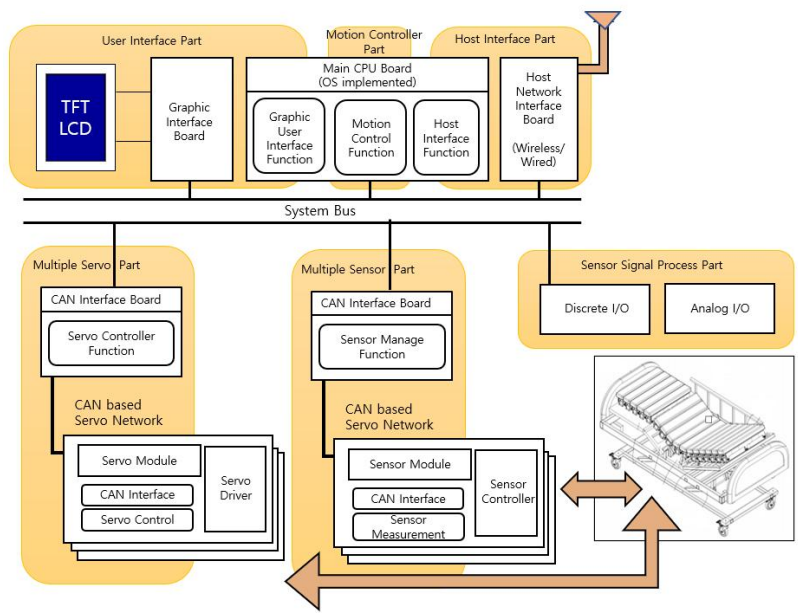


Figure 4. The Organization of the Main Controller

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data. A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier. The process of fuzzy logic is as follows: Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step [5, 6]. In this study, we employed a fuzzy controller to regulate the maximum pressure erroe of a key to be undet the critical ulcer pressure. The architecture of the fuzzy controller is like as shown in figure 5. The body pressure sensors are mounted on a key, and its height is controlled by a fuzzy controller. Figure 5 shows the FLS (Fuzzy Logic System), where P_{cu} is the critical ulcer pressure, P_{mi} is the maximum pressure of the key i, h_i is the height of the keyboard i, e_i is the error between P_{cu} and P_{mi}. And $u_i(= h_i)$ is the height of a key, that is, the position input.

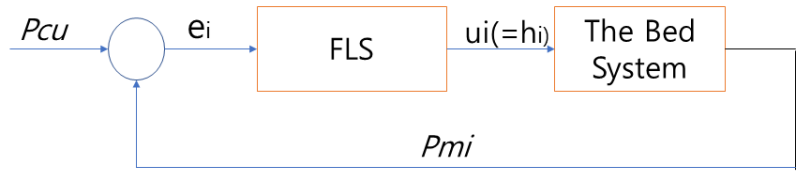


Figure 5. The FLS to Control Body Pressure

The error e_i is calculated as follows.

$$e_i = min(p_{mi} - p_{cu}, 0), i = 1,2, \dots N \tag{3}$$

Then, the total RMS (Root Mean Square) error can be computed as follows.

$$e_{RMS} = \sqrt{\frac{\sum_{i=1}^{N} e_i^2}{N}}, i = 1,2, \dots N \tag{4}$$

Where, N is the number of keys. The maximum pressure P_{mi} of the i-th key is as follows.

$$P_{mi} = \max\ p_{ij}, j = 1,2, \dots M \tag{5}$$

where, M is the number of pressure sensors in a key. In each key i, the pressure ratio R_i is computed as follows.

$$R_i = \frac{\sum_{j=1}^{M} P_{ij}}{\sum_{i=1}^{N} \sum_{j=1}^{M} P_{ij}} \tag{6}$$

In this work, we firstly propose a two-stage control method to prevent ulcer: the first one is the body pressure control by the fuzzy controller, and the second one is the duration time control by lifting the keyboard alternately. The duration time control is described as follows: when a key is down, the body pressure becomes zero and when it is up, the duration of up-state is in a short time such that the period of alteration is within 10 minutes [2]. Thus, there is no possibility of ulcer using duration time control.
Controlling ulcer while maintaining body comfort can be achieved through the first fuzzy pressure control, and even if not, ulcer can always be prevented through the second duration time control. Figure 6 shows the schematic flow of our two-stage control approach.

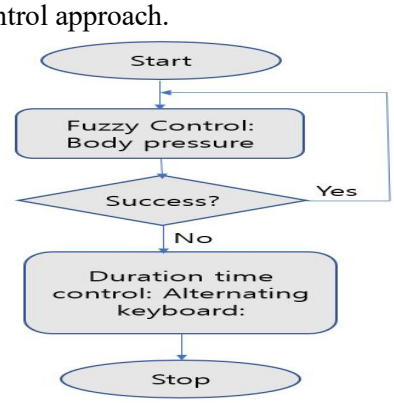


Figure 6. The two-stage approach of the developed controller

4. Implementation.

The developed medical bed consists of N keys, and each key is equipped with a BLDC motor that drives them. Each motor is equipped with a servo driver to enable the position and speed control of a keyboard. N servo drivers are connected through serial communication such as *CAN (Car Area Network).* The main controller

has two *CAN* ports, one is connected to *N* motor driver controllers in series, and the other to the body pressure sensor controllers (Figure 7). The pressure sensor is a kind of FSR (Force Sensitive Register) type thin film in which values are read as numerical ones. And the sensor controller on a key gathers the sensor information and sends it to the main controller.

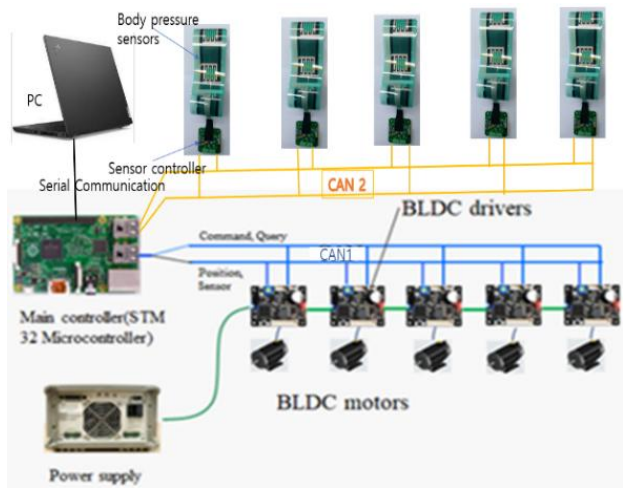


Figure 7. The Overall Structure of the System

The main controller commands the height value of each key to the *N* motor servo drivers as an angle through *CAN* communication, and reads the actual height value from the servo drivers. Similarly, the *M* body pressure sensor values on each key are read from the sensor controller and are transmitted to the main controller via *CAN*. The larger the number *NM* of sensor values, the greater the resolution of the body pressure map. *N* and *M* are limited for physical and practical reasons and they are set to 17 and 10, respectively.

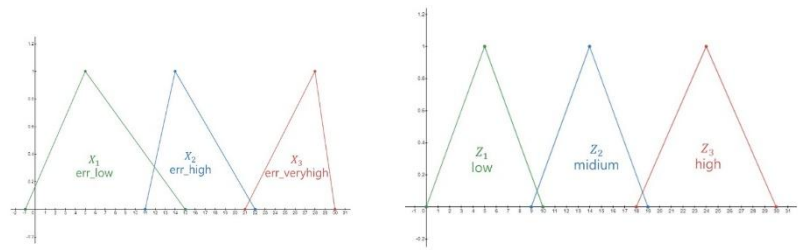
The length of the sensor line is 800mm, the thickness is 0.3mm. The sensor has a resolution of 12bit A/D conversion. The body pressure sensors are calibrated before use and they transmit the pressure value of the maximum 80mmHg to the controller. Figure 8 shows the overall structure of the system.

In this work, STM32F105 CPU, which embeds the Cortex-M3 core and supports two CAN ports, was employed as the main controller. It is connected with a PC, which installs a fuzzy control algorithm and communicates with the PC using the USB to UART converter.

5. Experimental Results

In the suggested method, the error e_i in (3) is the input to the controller, and the key height h_i in (1) is the output to the controller. The membership functions to the input and the output are as like in Figure 8 (a) and (b), respectively. The shape of the membership function is designed through experiments. The RMS error by percent is given as (7).

$$e_{ki} = \frac{\sqrt{Min(p_{cu}-p_{mi},0)^2}}{p_{cu}} \times 100, \text{ i=1, 2, …, N} \tag{7}$$



(a) Fuzzy Input **(b) Fuzzy Output**

Figure 8. Fuzzy Input/Output Membership Functions

Figure 9 shows the screen of GUI (Graphic User Interface). The inference of the fuzzy controller is done by the Max-Min method and the fuzzy rules are like as in Table1. Here, X is the error variable and Z is the height variation one.

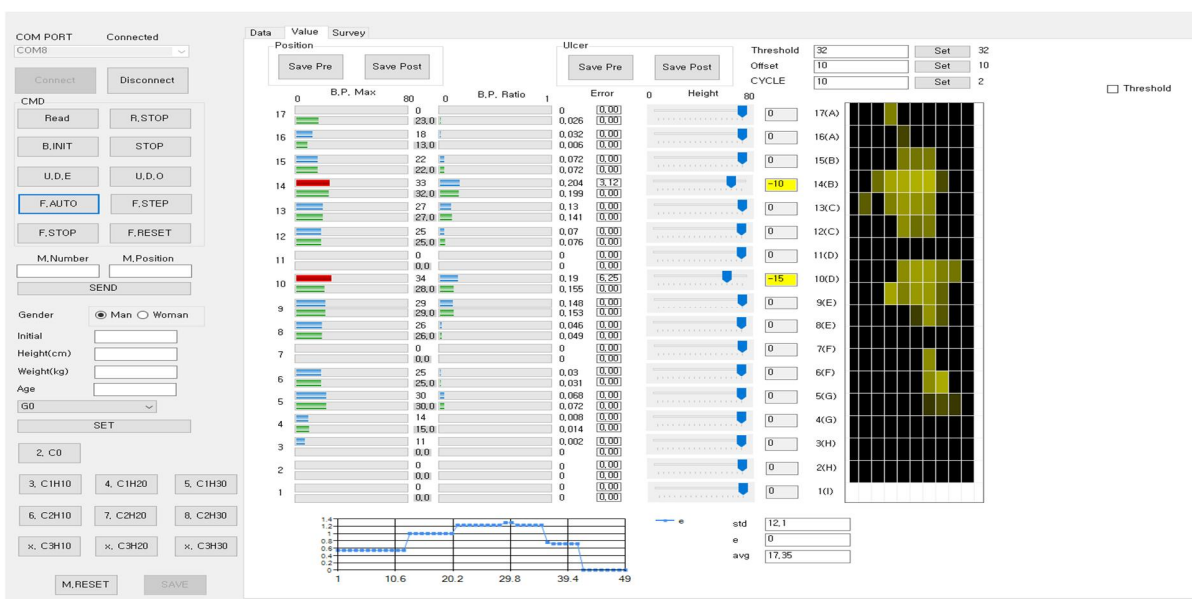


Figure 9. The GUI screen

Table 1. Fuzzy Rules

Rule	If-Then
R_1	If X is X_1, Then Z is Z_1
R_2	If X is X_2, Then Z is Z_2
R_3	If X is X_3, Then Z is Z_3

Using the Center-of-Gravity Method, the controller defuzzifies the output variable to get the final result. Equation (8) shows the Center-of-Gravity method.

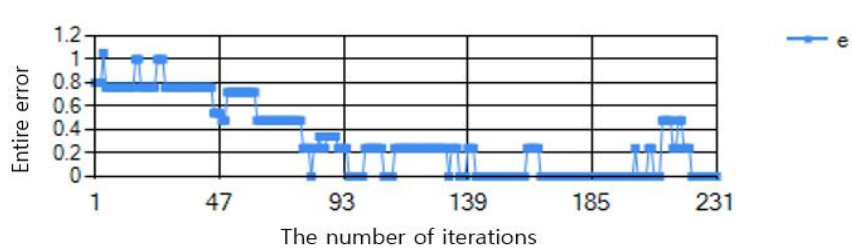
$$Z_i = \frac{\sum_{i=1} step \times (y_{left} + 4x_{center} y_{center} + x_{right} y_{right})/3}{\sum_{i=1} step \times (y_{left} + 4y_{center} + y_{right})/3} \tag{8}$$

Where, step = $(Z_{max} - Z_{min})/50$. The designed fuzzy control iterates the algorithm until the error becomes zero ($e_{RMS} = 0$) the resultant defuzzified value is added to the previous value. The experiment was done to a real person on the bed. and table 2 shows the results. In table 2, the key 10 and 14 exceeded the critical ulcer pressure P_{cu} (=32mmHg) and the errors occurred but the errors became zeros after 10 iterations of the closed control loop.

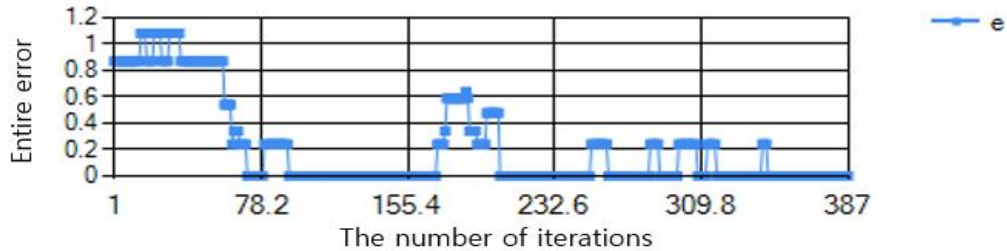
Table 2. Test Result

Key number	Error before control (%)	The Maximum pressure before control(mmHg)	The Maximum pressure after control(mmHg)l	Height(mm)
1	0	0	0	0
2	0	0	0	0
3	0	23	21	0
4	0	0	0	0
5	0	23	24	0
6	0	29	29	0
7	0	0	0	0
8	0	15	28	0
9	0	28	29	0
10	3.125	33	31	-5
11	0	0	0	0
12	0	20	24	0
13	0	25	30	0
14	28.125	35	32	-31
15	0	31	30	-15
16	0	0	0	0
17	0	25	31	-15

Figure 10 shows the errors in the supine posture and the side-lying one, respectively. They show the closed loop of the fuzzy controller works well. However, if the error does not converge to zero within the maximum predefined iteration number in the first fuzzy control stage, then the up and down motion of key alternation begins to start to prevent ulcer, which is the second stage control. Thus, there is no room for ulcer occurrence in our approach,



(a) Supine



(b) Side-Lying

Figure 10. The Error Log Samples

6. Conclusion

We developed the special 4 bar link mechanism of a medical bed to move the keys up and down. The keyboard has such 17 keys and each key has a sensor controller which reads body pressure information from 10 sensors on a key. Two CAN communication links in the main controller connect the 17 servo drives and 17 sensor controllers in two series, respectively. In this paper, we proposed a two-stage controller to prevent ulcer: the first one is the fuzzy controller which adjusts the body pressure to be within the critical ulcer one. The control aim is to reduce and disperse the maximum body pressure under the admittable one and to make the body comfortable. The second one is alternating the key movements automatically up and down within a short duration time. It works when the fuzzy control fails. Thus, the ulcer cannot theoretically occur using the proposed method. The experimental results show the effectiveness and validity of the proposed approach.

Acknowledgement

This work was supported by the 2020 Technology Development Program (S2926521) funded by the Ministry of SMEs and Startups of Korea

References

[1] H.S.Cho, J.C.Ryu, G.S.Kim, M.S.Mun and I.H.Lee, “Analysis of Body Pressure Distribution Characteristics According to the Design Factors of The Air-Cell Mattress for Preventing Decubitus Ulcer”, Journal of the Korean Society of Precision Engineering Vol. 21, No. 00, January 2004.

[2] Y.D.Lee, C.Y,Kim, C.J.Chang, M.S.Choi, J.A.Kim and J.Y.Lim, “The Control System of a Medical Robot Bed for Preventing Ulcer”, J. of the Convergence on Culture Technology, vol.6, no.3, pp353-359, Aug.31,2020.

[3] J.A.Kim, Y.D.Lee, H.K.Cho, “The Control System of a Robot Bed for Caring Pressure Ulcer”, Int. J. of Advanced Culture Techonology’,vol.8,no.3,253-258,2020, DOI https:/doi.org/10.1703/IJACT.2020.8.3.253

[4] Y.D.Lee, C.Y,Kim and M.S.Choi, “Enhancement of 4 Bar Parallelogram Linkage for a Medical Bed”, J. of the Convergence on Culture Technology, vol.6, no.1, pp.515-520, Feb.29,2020.[4] Fuzzy control programming. Technical report, International Electrotechnical Commision, 1997.

[5] J. Mendel. Fuzzy logic systems for engineering: a tutorial. Proceedings of the IEEE, 83(3):345–377, Mar 1995.

[6] K.H. Lee, Y.E.Kwon, H.J. Lee, Y.K.Lee, J.H.Seo, O.W.Kwon, S.H.Kang, and D.K. Lee, “Active Body Pressure Relief System with Time-of-Flight Optical Pressure Sensors for Pressure Ulcer Prevention”, Sensors 2019, 19, 3862; doi:10.3390/s19183862