Intelligent control of a modular power assisted stretcher for indoor application

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Abstract. This paper presents the development of an intelligent control of a modular power assisted stretcher movement on flat and sloped floors for indoor environment. Conceptual design techniques are used to select the best concept for prototyping power assist systems. The operator's movement intention and related voltage data is sensed by an Eight-axis hall effect sensor. It proposes the use of PID controller to optimize and maintain the velocity of the stretcher adapted to different weight and floor conditions. A stepping motor is applied to drive each wheel to respond appropriately to different floor and steering conditions (flat or sloped, straight section or turns). Without assistance it would be impractical for an operator to move a loaded stretcher (with patient and accessories) weighing up to approximately 100 kg on 15 degrees straight slope-up / slope-down floor sections. The power assist application turns this into an easy operation.

1. Introduction

Over the years, many countries, including Thailand have seen an increase of elderly people and a reduction in number of working age citizens [1][2]. Medical Health Service providers such as nurses, nursing assistants, that are tasked with the moving of patients have a heavy load to handle [3][4]. Moving a patient-loaded stretcher needs the assistance of at least two nurses (especially on sloped floors) [5]. Therefore, the auxiliary power system is an effective solution to reduce the number of stretcher operators to only one person per bed. In addition, in this study, the auxiliary power system is applied to the modular drive system, cancelling the need for drive units on other patient stretchers. As such, implementing this system results in a significant cost reduction. Therefore, the goal of this study is to provide a system to reduce the workload and the number of workers in hospitals and health care facilities.

2. Design Concept

There are two main concepts applied in this research. One is the prototype construction of a complete stretcher with power-assist system assembly. Another is a prototype of a modular stand-alone power
assist system without bed. Table 1 shows the design concepts according to the type of function. A selection process based on these design concepts will lead to further prototyping.

![Figure 1. Architecture of power assist system today.](image)

Different components make up power assist systems, including wheels (such as Omni directional or differential drive steering wheels), user interfaces (such as joystick [9], body motion, voice), navigation systems (such as radar, vision, magnet tape), different sensor types depending on applications, requirements and control systems as shown in Figure 1.

2.1 Functional of conceptual design

| System          | Design 1                          | Design 2                          |
|-----------------|-----------------------------------|-----------------------------------|
| User interface  | Potentiometer joystick            | Hall effect sensor joystick       |
| Localization    | none                              | WPS                               |
| Controller      | Electric DC motor Controller       | Arduino controller board          |
| Power Motor     | DC brushless motor                | Stepping motor                    |

The selection process on the design concepts depends on important principles, including hierarchical framework, priority analysis and by determining the parameters/criteria that are used to make decisions at the top level by showing the overall objective or goal [6]. A pairwise comparison is conducted based on a relative evaluation score level as shown in Table 2. Finally, the most suitable option is selected [7][8]. The parameters evaluated in this comparison are functionality-, safety-, price- and flexibility-targets. The results of the pairwise comparison of the criteria shown in Table 3 based on the score level outlined in Table 2.
Table 2. Relative score level of pairwise comparison.

| Scale | Definition    |
|-------|--------------|
| 1     | Equal value  |
| 3     | Slightly more value |
| 5     | Stronger value |
| 7     | Very strong value |

Table 3. Pairwise comparison of requirements.

| Requirement | Functionality | Safety | Price | Flexibility |
|-------------|---------------|--------|-------|-------------|
| Functionality | 1           | 1/7 = 0.14 | 5     | 1           |
| Safety      | 7/1 = 7      | 1      | 5     | 3           |
| Price       | 1/5 = 0.2    | 0.2    | 1     | 0.2         |
| Flexibility | 1            | 1/3 = 0.33 | 5     | 1           |
| Total       | 9.2          | 1.64   | 16    | 5.2         |

The relative importance of two selected criteria using pair-wise comparison is shown in Table 3. It shows the relative score level for pairwise comparison as shown in Table 2. For instance, if safety is rated to be a very strong value over functionality, then we got 7/1 = 7. The data for relative importance is extracted via questionnaires and knowledge about power assist systems.

2.2 Evaluation of the priority of functionality

The data from Table 3 is then synthesized to find the priority of the target requirements. This is calculated from the following equation (1):

$$W_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad \text{when } i,j = 1,2,\ldots,n$$

Table 4. Synthesized matrix related to functionality.

| Requirement | Functional | Safety | Price | Flexibility | SUM | Priority |
|-------------|------------|--------|-------|-------------|-----|----------|
| Functional  | 0.11       | 0.085  | 0.313 | 0.192       | 0.70| 0.175    |
| Safety      | 0.761      | 0.61   | 0.313 | 0.577       | 2.261| 0.560   |
| Price       | 0.022      | 0.122  | 0.063 | 0.038       | 0.245| 0.061   |
| Flexibility | 0.11       | 0.20   | 0.313 | 0.192       | 0.815| 0.204   |
| Total       |            |        |       |             | 1.000|         |

The results of the synthesis in Table 4 show the importance and weight priority that can be sorted as follows: safety (0.560), flexibility (0.204), functional (0.175) and price (0.061).

2.3 Pairwise comparison of sub-criteria

The next step is comparison of the level of selection of sub-devices such as user interface, control system and motor drive system. Score 1 or 2 was assigned to evaluate or compare which design is evaluated worst (score=1) or better (score=2). Table 5, Table 6 and Table 7 present the pairwise comparison of sub-criteria.
### Table 5. Pairwise comparison of the user interface unit of design 1 and design 2 (from Table 1).

| Requirement | (Design 2) Functionality | Safety | Price | Flexibility |
|-------------|--------------------------|--------|-------|-------------|
| (Design 1)  | 1/2=0.5                  | 1/2=0.5| 1/2=0.5|

### Table 6. Pairwise comparison of the control system unit of design 1 and design 2 (from Table 1).

| Requirement | (Design 2) Functionality | Safety | Price | Flexibility |
|-------------|--------------------------|--------|-------|-------------|
| (Design 1)  | 1/2=0.5                  | 1/2=0.5| 2/1=2 |

### Table 7. Pairwise comparison of the motor drive system of design 1 and design 2 (from Table 1).

| Requirement | (Design 2) Functionality | Safety | Price | Flexibility |
|-------------|--------------------------|--------|-------|-------------|
| (Design 1)  | 1/2=0.5                  | 1/2=0.5| 2/1=2 |

The importance or weight priority is used for calculation and selection of the best design from this equation.

\[
Y_i = W_i \times \sum_{j=1}^{m} b_{ij} \quad \text{when } i = 1,2,\ldots,n \ ; \ j = 1,2,\ldots,m
\]  

(2)

\[
Z = \left( \sum_{i=1}^{n} Y_i \right) / m \quad \text{when } i,j = 1,2,\ldots,n
\]  

(3)

Where

- \(Y_i\) is total score requirement-i of design 1 to design 2
- \(b_{ij}\) is summation of pairwise score of design 1 to design 2 from sub criteria-j
- \(Z\) is the final comparison score of design 1 to design 2

From equation (2) then we have,

- Functionality: \(0.175 \times [0.5+0.5+0.5] = 0.2625\)
- Safety: \(0.56 \times [0.5+0.5+0.5] = 0.840\)
- Cost: \(0.061 \times [0.5+2.2+2.2] = 0.2745\)
- Flexibility: \(0.204 \times [0.5+0.5+1.0] = 0.408\) respectively.

And from equation (3) \(Z\) is the summation score for design 1 versus design 2.

- \(Z = (0.2625 + 0.840 + 0.2745 + 0.408) / 3 = (1.785/3) = 0.595\)

Based on the synthesis of the criteria comparison results, it was found that the concept design 1 per concept design 2 was 0.595, which is not more than half (2 is half), therefore it can be concluded that the concept design 2 is appropriate to be used as a prototype concept for creating an intelligent control of an indoor modular power assist stretcher.
3. **Prototype Architecture**

The components to be provided for prototype assembly are presented here below:

- A Stepping motor is applied to drive each wheel (Front R-L and Rear R-L).
- Three-axis accelerometer is used for feeding back the angle of sloped floors.
- A vibration sensor 801S is used to feedback the signal for improving the smoothness of the stepping motor’s movement.
- An Eight-axis hall effect sensor joystick is used for controlling the direction and velocity of stepping motor.
- An Arduino 2560 controller unit to apply PID[10] controlling algorithm.
- Transformer Power source which transforms the 220 VAC power to 24 VDC.

![Communication diagram](image)

**Figure 2.** Communication diagram.

The software for detecting speed, acceleration and vibration signals has been created specifically for this work. The program analyzes the behavior of signals generated by the PID control system.

4. **Experiment**

The experiment is done on a fully loaded system (adding a person’s weight) of approximately total 100 kilograms. Hereby one operator controls the stretcher with a joystick, to move on flat and sloping hospital floors.

A mobile computer used to observe the operation signal of joystick, sensor and the behavior of motors. Figure 4 and figure 5 shows a signal graph with movement zoning A,C,D and F resulting from moving forward on a flat floor. The results show that the stretcher can move in the specified direction with relatively stable speed and acceleration. The speed is quite uniform in every direction of movement. The acceleration is found to have a constant ripple caused by the automatic adjustment with every 2% per degree of inclination. The uneven experimental conditions cause the sensor to send acceleration compensation signals to the control circuit resulting in the signal as shown in the graph.
Figure 3. Testing of the control system and motion behaviors.

Figure 4. Proportions of the speed, acceleration and vibration while moving upward.
Figure 5. Proportions of the speed, acceleration and vibration while moving downward.

Figure 4 is signal graph for moving upward (forward) on a sloped floor.

Figure 5 is signal graph for moving downward (forward) on a sloped floor. It shows the speed, acceleration and vibration that can be measured from the stretcher movement on a floor with zoning as follows:

- Zone-A and Zone-D is the time when the stretcher moves on a flat area.
- Zone-B is the time period where the movement changes from a flat area to a steep slope in an upward direction. It is found that the acceleration will gradually increase according to the angle of the floor. The control system will maintain a constant speed throughout the movement.
- Zone-C is when the stretcher moves on a steep slope in an upward direction when the acceleration increases to the appropriate value level according to the slope of the floor. Acceleration is constant.
- Zone-E Displays the time zone where the movement changes from a flat floor onto the slope in the downward direction, which indicates that the acceleration will gradually decrease according to the angle of the floor.
- Zone-F is the time zone where the stretcher moves on a steep slope in the downward direction and the acceleration is reduced to the appropriate value level according to the slope of the floor. Acceleration is constant.

5. Conclusion
First conceptual design techniques were used to select the best concept for prototyping power assist systems. We evaluated the operational efficiency of an intelligent control of a modular power assist stretcher operated with an 8-way joystick with hall effect sensors. The PID control of the electric stepping motor (the wheel drive system) has resulted in smooth, non-jerky movement with proper speed and acceleration finely adjusted to the specific floor inclination. The studied power assist technology shows great promise as an effective system with large economic impact for the health care facilities choosing to implement this device. The movement assisted stretcher can operate on half the manpower that would be needed to move a non-assisted stretcher. Our suggestion is for this valuable system to be developed continuously.
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