5-Position 4-Actuator Automated Bed To Prevent Bed Sores

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Abstract. Bedsores — also called pressure ulcers or decubitus ulcers — are injuries to the skin and underlying tissue resulting from prolonged pressure on the skin. For permanently bedridden patients (especially those paralyzed or in coma), bedsores are a problem which is usually either ignored or not dealt with properly. The effects of bedsores can be very severe when it reaches higher stages (stage 3, stage 4) below the surface of the skin, even exposing the bones. The causes of bedsores are pressure, shear and friction where pressure plays a significant role and hence are known as pressure ulcers. When a person lies on a bed for a prolonged period of time, the pressure at body parts such as the tailbone, shoulder blades, heels, ankle, skin behind knees restricts blood flow at these points which in turn results in sores. Taking care of patients affected by bedsores is a trying process for the nurses or the caretaker. Either by distributing the pressure throughout the body or by shifting the pressure points frequently, the occurrence of bedsores can be delayed or prevented. Hypnos employs the latter principle to prevent the development of bedsores by attaining five different positions.

Keywords. Automation, Healthcare, Bedsores, Kinetic nursing, Transforming bed, Bedridden patients, Pressure ulcers, Tilting bed, Automated bed, Robotic bed.

1. Introduction
Bedsores, otherwise known as the pressure ulcers or decubitus ulcers, are injuries to the skin and the underlying tissues resulting from prolonged pressure on the skin [1]. Bedsores most often develop near pressure points i.e., the skin that covers the bony areas of the body. It is estimated that an average human shifts the sleeping position for every 11.6 minutes to prone, lateral recumbent or supine positions [4]. So, people most at risk of bedsores are those with a medical condition that limits their ability to change positions or those who spend most of their time in a bed or chair. Due to their inability to change positions, the insufficient blood flow causes blood clots in areas that are under high pressure, thus resulting in bedsores. Bedsores can develop quickly, especially when there is a disorder or when the patient is injured. Most sores heal with treatment, but some never heal completely. Steps can be taken to help prevent the development of bedsores and aid healing. Hypnos will be one such product that helps
to prevent the development of bedsores. The aim of this paper is to address the limitations of the existing products, which includes high cost and high noise level due to the compressors. Some of the current products are Oscillatory bed support [3], Invacare 5310IVC electric bed with Micro air MA90, Microair, Toto, Alpha Care APM2 Lateral Turning Mattress, Flex bed, Mechanism for moving bed, Invacare G-Series Bed, Patient Undersheet [6].

2. Background
Pressure against the skin limits blood flow to the skin, which leads to the development of bedsores. Other factors associated with limited mobility can make the skin vulnerable to damage and can also contribute to the development of pressure sores. Three main factors for pressure sores are:

- **Pressure**: Blood flow is essential to delivering oxygen and other nutrients to tissues. Constant pressure on any part of our body can lessen the flow of blood to tissues. Without the vital nutrients, skin and nearby tissues are damaged and might eventually die. 10 kPa of pressure causes tissue death. For people with limited mobility, such pressure tends to occur in the pressure points, which are regions that are not well-padded with muscle or fat and that covers a bone, such as a spine, tailbone, shoulder blades, hips, heels and elbows.
- **Friction**: There will be friction when the skin rubs against clothing or the bed. It can make soft skin more vulnerable to injury, especially if the skin is not dry.
- **Shear**: Shear is relative motion between two surfaces moves in opposite directions. The skin covering the bone might stay in place, as the tailbone moves down, essentially pulling in the opposite direction.

Pressure sores are prone to develop on the skin over the following regions for those who use a wheelchair:

- Tailbone or buttocks
- Shoulder blades and spine
- The rear side of arms and legs where they rest against the chair

Following are the common sites of pressures sores for bedridden patients:

- Back or sides of the head
- Shoulder blades
- Hip or lower back of tailbone
- Heels, ankles and skin behind the knees

3. Solution

3.1. Primary Objective
To design an automated bed that can shift the pressure points of a patient periodically to prevent the development of bedsores. The bed is to be much cheaper than commercially available methods.

3.2. Working Principle
The supporting structure of all the components is a simple modification of a conventional cot. The head and tail stands are retained, while the plate of the conventional bed that supports the mattress is modified to a rectangular frame with 'L' cross-section, on which the mattress supporting plates rest at resting position (when all the actuators are at full retraction). Four linear actuators are used which are positioned as shown in the sketch below and are controlled by Arduino Uno to automate actuation and to change positions periodically. The actuators actuate two bars that lie longitudinally along the line containing actuator 1&3 and actuators 2&4. These bars consist of three segments that are connected using hinges, and these hinges can be constrained using pins. The mattress rests on these plates. When the bar is
moved, the plate moves along with it, and so does the mattress. Below is a list of combination of actuators to obtain required motion:

- 1 & 3 (with pin engaged) – tilt left
- 2 & 4 (with pin engaged) – tilt right
- 1 & 2 (with pin disengaged) – sitting up
- 3 & 4 (with pin disengaged) – knee comfort
- 1 & 2 (with pin engaged) – Trendelenburg head up
- 3 & 4 (with pin engaged) – Trendelenburg head down

![Figure 1. Position of linear actuators.](image)

### 3.3. Setup and component description

**Table 1.** Setup and component description.

| Component       | Description                                                                 |
|-----------------|-----------------------------------------------------------------------------|
| Side frames     | 2 side frames made of mild steel pipe of diameter 30mm, 2mm thick            |
| Bottom support rods | 2 hollow mild steel square pipes (80x80 mm) of 2100 mm length 5 mm thick, welded to the side frames |
| Top support rods | 3 pairs of mild steel hollow square pipes (80x80 mm), 5mm thick for the torso (900mm), middle (450mm) and leg portion (600mm) |
| Support plates  | 3 wooden plates for each pair of support rods (20mm thick & 785mm wide)     |
| L frame         | 5 mm thick mild steel frame on which the plates sit                         |
| Universal joints| 8 Chromoly universal joints to ensure 2 DOF for the actuators                |
| Latches         | Provided to lock the middle plate with the top and bottom plates            |
| Side flaps      | Adjustable Foam side flaps provided to prevent sliding of the patient      |
| Castor wheels   | Load bearing nylon castor wheels                                            |
| Mattress        | Multi-density articulated mattress made of different grades of polyurethane |
3.4. Design and configuration

Figure 2. Final Design.

Hypnos is an automated bed to prevent the development of bedsores. It is operated with 4 linear actuators and a specially designed three plate platform system. This three-plate platform system consists of three support plates made of wood and two sets of three support rods running under either side of each plate. These support plates and support rods are attached to each other by means of clamps and are rigidly held together. The actuators are in turn connected to these support rods by using universal joints, such that it has two degrees of freedom. There are latches provided which can lock the middle support plate to head and leg support plate individually. The actuators are positioned such that different combination of actuation of the four actuators gives five different positions:

- Sitting - In this position, the torso of the body is lifted such that the person appears to be sitting. This position is used to feed the patient and to take care of the patient.
- Left tilt - In this position, the body is tilted to the left hand side of the patient.
- Right tilt - In this position, the body is tilted to the right hand side of the patient.
- Trendelenburg- In this position, the head is lifted up, and the leg remains down so as to make a straight slanting figure; ensures normal blood flow.
- Reverse-Trendelenburg – This is exactly reverse of Trendelenburg where the leg goes up, and the head is down creating an exactly reverse slant.
3.5. Basic Algorithm

![Workflow Diagram](image)

**Figure 3.** Workflow.

3.5.1. Position Feedback:

All four linear actuators have to be controlled independently to get different modes. The length of actuation required for each Linear actuator for a particular mode is determined from Kinetic nursing guidelines. Once the user input is given to the microcontroller for a specific mode, the actuators will be powered by switching relays. A Reed switch is used to provide position feedback to the microcontroller. Reed switch which is placed near the rotary part of the actuator motor. There’ll be a permanent magnet on the circumference of the rotating part of the motor in each rotation the permanent magnet will come closer to the reed switch once. Whenever the permanent magnet comes closer to the reed switch, it will become open circuit. So, when we plot the graph of reed switch against time when the linear actuator is moving, we will get a square wave. The number of steps in the square wave is proportional to the length of the actuation. The output wave from the reed switch is given to the microcontroller as feedback for positioning the linear actuator.

![Reed Switch Diagram](image)

**Figure 4.** Reed switch [5]
3.6. **Analysis**

The load-bearing components of Hypnos are analysed for failure and to find the factor of safety in Ansys 18.1. On applying a load of 200N per actuator at the points of interest the following stress variations and deformations were observed. The deformation is not more than 2 mm in the exaggerated scale.

**Figure 5.** Output wave from the reed switch.

**Figure 6.** Deformation analysis.
4. Impact

In most cases of medical conditions like paralysis or coma wherein the patient is bedridden, either the nurse or one of their family members is obliged to frequently shift the position of the patient for uniform blood flow. This process becomes cumbersome and hectic and also becomes expensive, considering the fact that the caretaker must be paid. None of the existing products pays itself in this regard. With this notion, Hypnos has been designed such that it is automated, thus avoiding a person to look after the patient throughout the night. Provided the fact that in India, paralysis prevails among 0.89% of the population, i.e., for approximately 9,585,635 people, Hypnos will be a perfect product for the Indian society. The following data shows the possible expenditure in the absence of a product like Hypnos:

4.1 Stage IV Pressure Ulcer
In the case of Stage IV, pressure ulcers, skin flap surgery is necessary. At this stage, the chances of recurrence are very high. The muscle flap surgery costs around 44,00,000 INR and also loss of time.

4.2 Pneumonia
The pressure ulcers are associated with infectious complication, for example, pneumonia, which can lead to additional cost up to 30,00,000 INR.

4.3 Personal Care Attendant
Pressure ulcers can demand personal care assistants, which can further increase the cost significantly.

. Figure 7. Stress analysis.
5. Salient Features

- Ensures comfort. Activities like cleaning the patient, carrying out physiotherapy, etc. can be performed easily.
- Compatibility. The adjustable side flaps make the bed compatible with different sizes of patients.
- User-friendly interface. The interface is simple and easy to understand. It doesn't need any specific skill to operate the device.
- Fully automated. It reduces human labour (especially at night). Hence, it enhances the mental and physical health of the patient and caretakers.
- 100-fold cost reduction. The existing solutions range in cost between 25- 50 lakh rupees. While the unit cost of production of Hypnos is 37,000 INR.
- Multiple positions and states. Five different positions, namely Trendelenburg, Reverse Trendelenburg, Right tilt, Left tilt and sitting positions, are achieved.
- 100% prevention of bedsores.

6. Scope of Improvement

The following are some areas of improvement:
- Actuation control by conscious patients.
- Retractable side flaps to make it easy to place and shift the patient from the bed.
- Accommodation of other medical facilities in the structure.
- Developing into an aesthetic product.
- Feedback based control system.

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