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Development of a Semi-Automated Device to Lift and Transfer Bedridden Patients

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Abstract: Transferring bedridden patients from one flat surface to another, i.e. from a bed to a stretcher or laboratory/theater bed, is one of crucial activities carried out in healthcare facilities. It is a physically challenging task with many concerns on patient's safety and comfortability. None of the existing methods used for that task provides effective solution. Hence, this study aims at providing a mechanism to transfer bedridden patients with greater safety and comfort while reducing the human involvement.

The study was carried out in four phases. Initially, data collection was carried out to identify variety of methods, devices used for patient transferring both locally and globally. Further, a survey was done to identify main factors affecting when performing a transfer by interviewing all stakeholders of the activity including doctors, nurses, attendants, lab technicians. Secondly, design phase was completed. Thirdly, designed device was fabricated and finally, it was tested to refine and improve further. Developed design is a semi-automated device which needs only one operator to operate. When using it, patient's orientation is not required to change, and no any human effort needed. All the lifting and transferring movements are matched to standards given by WHO. Machine was tested using real size dummy as the patient and feedback was obtained from variety of medical staff involving with patient transferring. Qualitative data collection was done on performance. As per the feedback on testing, device is capable of providing a safe, comfortable and less physically demanding mechanism to transfer bedridden patients.

Keywords: Patient transferring, Automation, Elector-mechanical device, Safety

Introduction

Healthcare industry has evolved greatly due to the technology development. It has improved the efficiency, accuracy, safety, comfortability and effectiveness of large spectrum of activities in the sector from diagnosing illnesses to performing brain surgeries. One such area is handling patients in healthcare institutions.

A person, who is bedridden with physical disabilities, is vulnerable to various health complications like fractures, bedsores and depression due to lack of motion for long periods. Hence, they are both physically and mentally strained. On top of that, a bedridden patient needs to move from one place to another for various requirements such as medical testing/operations, personal hygiene etc. Lifting and transferring of patients in that condition is quite difficult, challenging and risky task.

There are number of factors to be considered when handling a bedridden patient, namely safety, comfortability of patients, physical effort required from handler. Safety is the utmost important factor which always considered as the priority. Due to safety concerns, handling of bedridden patients is performed variably depending on the condition of the patient.

However, when safety comes first, it comes with a trade off with comfortability. Even though handling crew perform the tasks with good care, patience and understanding, maintaining comfort when transferring is a greater challenge in the present context. In order to improve both safety and comfortability, one of the practices is having 4-6 number of staff members for the task. Yet, that alone can reduce comfortability and safety when proper coordination is absent. Thus, to reduce the human effort needed, different devices have been employed.

To date, there are various types of bedridden patient handling methods have been developed. Slider sheets, transfer belts, slider/transfer board and rolling slider/transfer board are few of such. However, they have number of drawbacks. Due to unavailability of an effective transferring method, both medical crew and patients face numerous difficulties. Thus, this study is focused on filling that void by developing an effective mechanism to transfer bedridden patients safely and comfortably with minimal human effort.

Literature Review

A. Factors Affecting a Safe and Comfortable Patient Transfers

Due to the growth in old age population, patients who confined to a bed because of old age and various illnesses have risen in recent past (R. Sheng et al., 2017). In addition, requirement for transferring patients from one support to another, one place to another has also increased with numerous medical requirements. Hence, patient handling is a crucial task that needs more attention for improvement.

Patient transferring has been categorized based on level of support needed from an outsider. There are three types,

- Independent transfers: In this, no any support from outside is needed
- Assisted transfers: Patient actively participates to the transfer, yet caregiver' s assistance needed.
- Dependent transfers: Caregiver performs the whole transferring act while getting no or minimal involvement of the patient.

For assisted or dependent transfers, level of involvement of caregiver can be stand-by assist or minimal, moderate and maximum assistance. Bedridden patients undergo either assisted or dependent transfers.

In order to have a safe patient transfer, risk factors associated with patient, setup and instruments have to be identified and properly managed. In relation to the condition of the patient, his ability and level of communication, cognition (memory, judgement etc.), medical status (diagnosis, pain, supported devices, medication etc.), physical status (weight, height, balance, range of motion) and emotional status (resistive, aggressive, supportive, unpredictable etc.) are critical factors to be considered. Moreover, layout of the premises, space availability, lighting condition, obstacles and floor are few of the factors listed under setup. Moreover, risk factors associated with instruments include, improper use of instruments or use of faulty ones, wrong calibrations, inadequate training for use of equipment, attached life supports. Thus, formulating a safe and comfortable handling methods for bedridden patients' needs consideration of wide range of factors.

B. Transfer Assistive Devices

In the literature, wide range of patient transfer assistive devices and methods have been proposed. These includes sliding sheets, transfer belts, slide/transfer boards and rolling slide/transfer boards. However, in modern times, technology has been used to develop devices which need less human effort. These devices can be mainly categorized in to two based on the method they use. Lift-sliding transferring method and horizontal moving method.

Under the first category, lift-sliding transferring, number of different mechanisms have been developed Xu K., et al., 2016, Jiang JG et al., 2016). Xu K., et al., (2016) has proposed a portable patient lifting mechanism as shown in Figure 1. This includes worm gear arrangement to lift patients while grabbing is done using opening and closing hand grasping mechanism. It has a simple structure and occupy less space but have limitations of adjustment requirement of lifting height and grasping has made it less usable.

Conversely, a patient transferring robot has been developed by Jiang JG, et al. (2015). This mechanism driven by two screws to lift and transfer. Main advantage of this is when transferring, patient's original posture can be maintained. However, due to cantilevered nature, device has to be larger.

In the second category, horizontal movement method, Figure 2 shows one of the methods proposed. It mainly uses U-rail to horizonal transfer of patients from hospital bed to transferring bed and from that to operating bed. However, this demand few retrofits to hospital bed and other connecting supports. Even though it gives more stable transferring it needs retrofitting when use for different setup.

R. Sheng, et al. (2017) has provided number of recently developed patient transferring mechanism and reviewed their advantages and disadvantages.

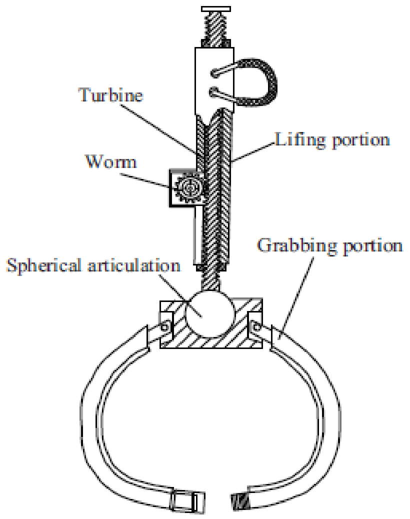

Figure 3. A portable patient transferring apparatus

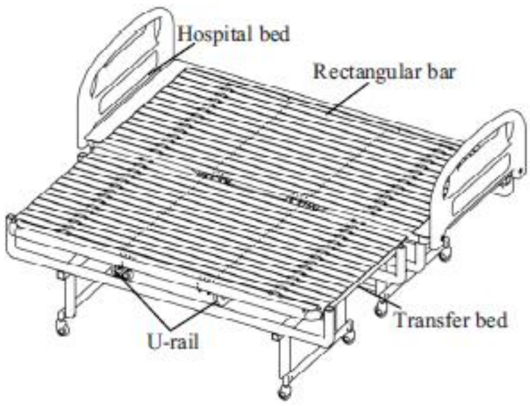

Figure 2. A translational patient transferring device

Methodology

Figure 3 shows the methodology followed in this study. Firstly, a survey was conducted to collect data on current practice of transferring bedridden patients. It was carried out in University Hospital KDU. Following data were collected through structured questionnaires and interviews conducted covering all stake holders of the activity.

- Current methods used
- Arrangement of wards and their layouts
- Experiences of medical crew on handling bedridden patients and challenges faced
- Different transferring requirements

Initially, required features of the patient handling device were gathered. Smooth operation, high accuracy, ease of controlling, withstanding high loads, less noise and low cost are the main factors highlighted.

In terms of methods used, it was observed that only transfer boards are used in local hospitals. This is a manual process which needs minimum of 3 caregivers' involvement. Additionally, ward beds, theater beds and trolleys were observed for their operations and powered alternatives. One of main findings was electrically driven machines provide smooth movements which is ideal for medical conditions.

Another observation was the value of the HMI (human machine interface) in machines. Both ICU bed and the theater beds use HMI to give instructions to the control unit of the machine. It provides user-friendly mechanism for the operator to control the machine easily. HMI interlinks the operator and the device. Actual components and the functions can be created inside the HMI. Because of that it is very easy to use without having much more knowledge on technical background of the machine.

After collecting all the required data, design, fabrication and testing phases were completed which are discussed in detail in the following sub sections.

A. Design of the Machine

The 3D model of the final design of the machine is given in Figure 4. The maximum operational area and the general dimensions are determined based on standard ward layouts of hospitals. The maximum load that the machine can handled is set to 100 kg. The Device consists of six assemblies denominated as machine base, dynamic structure, machine bed, lifting and transferring units, lateral transferring and controlling unit.

Initially air mattress is placed between the patient and the surface of the bed. Air mattress is inflated by the air blown into it. After placing the device, height can be adjusted to the required level Cotton strips are connected to the mattress manually. AC electric motor provides rotational motion to the transferring shaft. When strips wind, patient is transferred to the machine bed with air mattress. Lateral transfer plate is able to move towards the bed and safely transfer the patient to the bed.

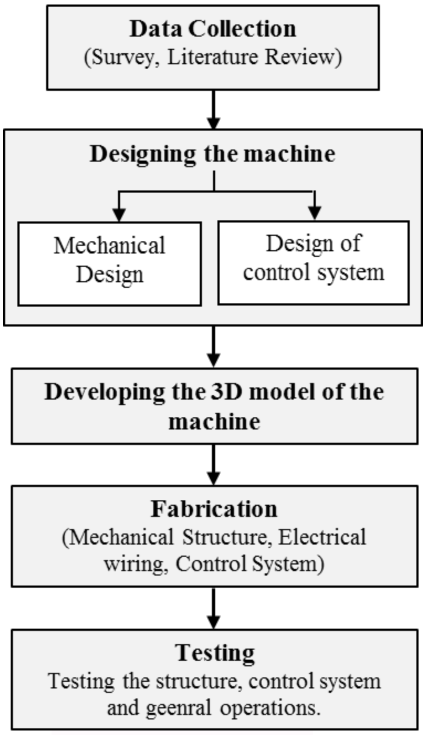

Figure 3. Methodology

Figure 4. 3D Model of the machine

Power requirements of all motors which were used for lifting, lowering and lateral transferring are calculated using equation (1).

$$P = \tau\omega \quad (1)$$

To adjust the height of the machine bed special mechanism is used. Similar mechanism to the cam mechanism is used for the dynamic structure. Purpose of selecting this mechanism is to minimize the axial thrust on lead screw. Two triangles were designed to achieve this cam motion. One metallic triangle is able to rotate around its horizontal axis. Another triangle is mounted to the eccentric position, because of that when lower triangle rotates around its horizontal axis upper triangle is able to achieve linear upward and downward motion.

AC geared motor with lead screw was mounted to the cross-link shaft. When the motor rotates leadscrew achieve rotational motion. Nut is mounted to a hollow shaft which is mounted to the cross link of the dynamic structure. Screw is mounted through the nut. When the screw rotates nut achieve linear motion. In the clockwise rotation of the motor, nut gives an axial thrust to the cross link through hollow shaft. In counterclockwise rotation of the motor nut gives pull to the cross link. From this push and pull machine bed achieves its upward and downward motion. Because of this motion height adjusting is possible. Device is designed for maximum load of 1000 N on the machine bed. Equivalent load with other components is 1250 N.

For lifting and loweing the mechanism, double start screw has been used. Diameter and the pitch of the screw respectively 20 mm and 2 mm. Torque required to raise the load is given by the equation,

$$T = w\left(\frac{Tan\alpha + Tan\varphi}{1 - Tan\alpha . Tan\varphi}\right)\frac{d}{2} \quad (2)$$

$$Tan\varphi = \frac{\mu}{Cos\beta} \quad (3)$$

$$Tan\alpha = \frac{Lead}{\pi d} \quad (4)$$

(w: load to be lifted, T: required torque of the motor, α: helix angle, μ: coefficient of friction between the screw and nut, d: mean diameter of the screw)

$$Tan\alpha = \frac{2 \times 4}{\pi \times 20} = 0.127$$

$$Tan\varphi = \frac{0.15}{Cos15°} = 0.155$$

$$T = 1250\left(\frac{0.127 + 0.155}{1 - 0.127 \times 0.155}\right) \times \frac{20}{2} = 35.95\ Nm$$

Torque required to lower the load is given by,

$$T = wTan(\varphi - \alpha)\frac{d}{2} \quad (5)$$

Here, φ > α therefore self-locking of the screw secured.

Lateral transferring is done by, winding strips around upper cross bar. Friction force between the transfer mattress and the bed creates a resistive torque to the applied torque from the motor. Friction force between the transfer mattress and the bed can be written as in the form:

$$F = \mu R \quad (6)$$

(F: friction force between the transfer mattress and the bed, μ: coefficient of friction between fabric surfaces, R: Reaction force to the applied load on mattress)

Strips attached to the mattress and the winding shaft is 30º inclined to the horizontal plane.

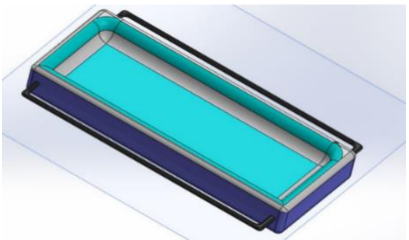

Figure 5. Transfer mattress

Required torque for lateral transferring can be written as in the form:

$$\boldsymbol{T} = (TCos30° + TSin30°)d \quad (7)$$

(**T**: required torque of the motor, T: Tension of the strips, d: diameter of the shaft)

$$\boldsymbol{T} = (0.56 \times 1000 + 1000)0.02 = 31.2\ Nm$$

Transfer mattress is an air mattress which is inflated with compressed air. In the proposed design, for the transfer mechanism inflated air mattress is used to avoid the direct contact with the patient and the rough surfaces of the machine and medical bed and to provide more comfortable transfer to the patient.

Device consist of two AC motors and one DC motor. Main functions of the machine are,

1. Elevating the bed
2. Lowering the bed
3. Linear forward motion of the bed
4. Linear backward of the bed
5. Clockwise rotation of the conveyer (Roll in)
6. Anti-Clockwise rotation of the conveyer (Roll out)

Controlling of the machine is done by Arduino Mega 2560, relay modules and L298 DC motor drive. DC 10A power supply was used to power electronic components and DC motor.

B. Stress Analysis

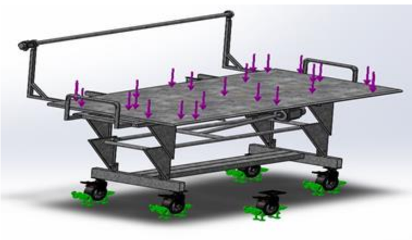

Figure 6. Application of 1000 N on machine bed

Figure 6 shows stress and material distribution of the device for applied 1000 N distributed load on the machine bed. Deflection of the cantilever lateral transfer plate is 0.3 mm at maximum distance. Stress in dynamic structure and most critical parts were in safe region. Stress analysis proved that the structure of the device withstand maximum applied force condition and device is safe for all applied force conditions below 1000 N.

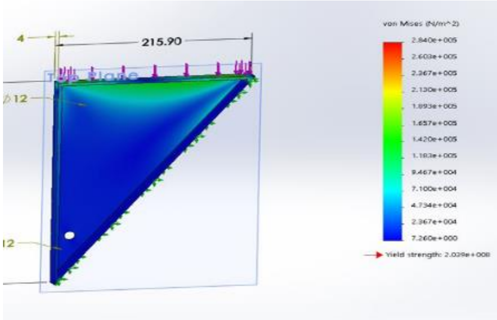

Figure 7. Stress distribution in dynamic structure

C. Fabrication

optimal dimensions and materials for the fabrication is obtained from aforementioned design calculations. Most of the subassemblies were made of galvanized steel box bars and sheet metal. Entire components of the machine are mounted on the base. Caster wheels are mounted to the machine base which making the device portable. Base of the machine made of 2mm thickness galvanized steel box bars. Thickness of the box bars and the material were selected to the withstand the force and stress acting on the machine.

Caster wheels are able to achieve rotational motion around its vertical axis and the circular motion around it's horizontal axis. Wheels can be locked in desired position which holds the whole machine at a steady position. To join the ribs and webs of the chassis welded joints were used as fabrication method. 3mm thickness sheet metal was selected for fabrication of this triangle to withstand dynamic and fatigue stresses. Eight triangle sets were interlinked using ¾ mm galvanized hollow steel pipes. Because of these interlinks all four triangle sets work together.

On top of the machine bed lateral transfer plate is mounted. Structure of this plate is made of one-inch square box bars. This steel structure was covered galvanized quarter millimeter thickness sheet metal plate. This provide a smooth surface to slide the transfer bed on the lateral transfer sheet. In front of this lateralled transfer sheet metal nose was mounted using reverted joints. Riveted joints were used to mount sheet metal plate to the box bar structures. This inclined plane provides a supportive surface to take the transfer mattress from the medical bed to the machine bed.

Figure 8. Lateral transferring unit with complete machine structure

A lead screw is mounted to the lateralled transfer sheet. Ball screw was used for this purpose. To the end of the ball screw DC motor is mounted using gear wheels. Gear wheels were fabricated using bronze alloy. Gear wheels were tempered to increase its properties. When the DC motor rotates it provides a rotational motion to the ball screw. Ball nut is mounted to the lateral transfer sheet. Because of that its rotational motion is restricted. Therefore, when the ball screw rotates ball nut achieve linear motion because of this linear motion lateral transfer sheet is able to achieve forward and backward motion in horizontal plane.

To guide the lateral transfer sheet two metallic rails were used. For this rails 3mm thickness iron plates were used. Plates were cut and bend using the hydraulic metal cutter and bender machine. Linear guides were mounted to the lateral transfer sheet. For each linear guide six bearings were used. To avoid the movement and ease the motion two nylon wheels were used.

Transfer the patient from the medical bet to the machine bed, special kind of mechanism is used in this machine. A shaft is mounted to the machine structure with the support of the bearings. These bearings provide the mount and enables the rotation of the shaft. One end of the shaft is mounted to an AC motor. Stripes were used to link this rotating shaft and the transfer mattress. When the shaft rotates strips wind around this shaft. Because of that length of the stripes gradually decreased. Therefore, tension in strips will be increased. Because of this tension created by the strips acting on the transfer mattress, it tends to move toward the machine.

To enhance the appearance of the patient lifting and transferring machine and to prevent corrosion of the metallic parts painting was done. When the paint is applied, contact of the metallic parts with the oxygen and moisture are avoided. In order to avoid corrosion, welded joints were grinned well to clean and remove the rust. Then metal filler was applied. Surfaces were smoothened using sandpapers. When required smooth surfaces are obtained metal primer was applied. Then lacquer was applied according to the color of various components. Blue color was applied to the machine bed and white color was applied to other components because it provides more comfortable vision to eyes.

Figure 9. Semi automated patient transfering device

D. Testing

Device was tested with 1000 N load as the maximum load applied. Obtained test results were considered in optimization of control system. Machine is operated by the AC 220 V, 50 Hz power supply. 10 A DC power supply converts AC into DC and power the electronic control unit. Program code, delay time, relay operation and HMI instructions were ensured in testing of the device. Visual inspection was carried to analyze the physical condition of components.

To enhance the effectiveness of the evaluation process, feedback of the different categories in health care industry towards the patient lifting and transferring semi-automated device was evaluated by a points system. Five major outcomes of the device were listed and given to the relevant category in health care industry for their feedback. They are allowed to give a value between one to ten (1-10) for each outcome according to their judgement. Four members were taken from each category for the evaluation process.

Table 8: Points table

Category	Identification	Patient Safety	Patient Comfortability	Ease of use	Flexibility	Reducing Human Effort
Doctor	D_1	9	9	9	7	9
	D_2	8	8	9	8	9
	D_3	8	8	9	7	9
	D_4	8	8	8	7	9
Nurse	N_1	7	7	7	7	9
	N_2	8	8	8	7	8
	N_3	7	8	8	7	8
	N_4	8	7	8	7	8
Care Givers	C_1	7	7	7	8	8
	C_2	7	8	7	7	7
	C_3	8	7	7	7	7
	C_4	7	7	7	6	8
Technician	T_1	8	8	8	7	8
	T_2	8	7	8	6	9
	T_3	7	8	8	8	9
	T_4	7	7	8	7	8
Sum of Points	16	122	122	126	113	133
Total Points		160	160	160	160	160
Percentage (%)		76.25	76.25	78.75	70.625	83.125

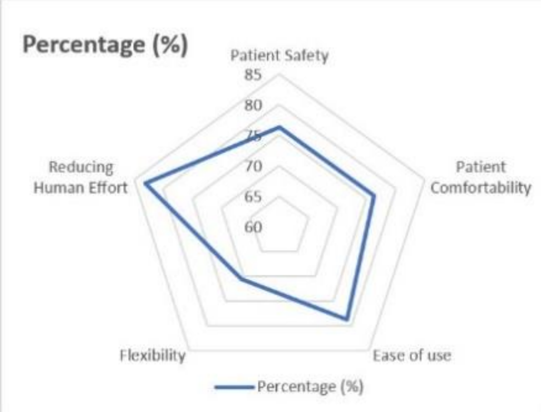

Figure 10. Summary of test reuslts

Discussion and Conclusions

Lifting and transferring a bed ridden patient is a quite difficult and risky task. To avoid the difficulties of this process various kinds of transferring methods and equipment are introduced. Risk and difficulties produced mainly due to the drawbacks of conventional transferring methods number of human involvements for the process is very high. Person who involves with this process should have a specific knowledge and proper training before to do this successfully. This research aimed to find a solution for a safer, less human involvement and comfortable patient transferring process. Thus, a semi-automated patient lifting and transferring machine for bed-ridden patients was designed and developed in this study. This device is an electro-mechanical device which can be operated by one person. The device was designed by gathering main requirements and concerns of all stakeholders of the process.

This machine has increased reliability and accuracy in operations when compared to existing devices. Furthermore, compact design, compatibility and user-friendlyness are also highlights of the proposed design. A qualitative testing was done using various stakeholders of the process to verify the operational performance of the device.

Acknowledgment

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