POWERED STRETCHER FOR PATIENT TRANSFER

By:

LEE SHEA WEN

(Matrix No: 142877)

Supervisor:

Professor Dr Zaidi Bin Mohd Ripin

July 2022

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfilment of the requirement to graduate with an honours degree in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed………………………….. (LEE SHEA WEN)

Date……………………………. 10/8/2022

Statement 1: This journal is the result of my own investigation, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

Signed………………………….. (LEE SHEA WEN)

Date……………………………. 10/8/2022

Statement 2: I hereby give consent for any journal, if accepted, to be available for photocopying and for interlibrary loan and for the title and summary to be made available outside of organizations.

Signed………………………….. (LEE SHEA WEN)

Date……………………………. 10/8/2022

ACKNOWLEDGEMENT

First of all, I would like to express my deepest gratitude to my supervisor, Prof Zaidi Mohd Ripin, for the encouragement, guidance, and suggestion throughout the ongoing project. It has been a great experience to be under his supervision as he thoroughly guides me, shares his expertise, and provides me with precious hints. It has been a great experience to be able to work with him, and I learned a lot of new things from him throughout this project.

Next, I would also like to thank Dr Muhammad Fauzinizam Bin Razali, who is the coordinator of EMD 452, for the preparation of guidelines for conducting research and thesis writing. Dr Fauzi also arranged several workshops to help students with thesis formatting.

Besides that, I also want to extend my sincere gratitude to the Assistant Engineers from the School of Mechanical Engineering, Universiti Sains Malaysia, Mr Baharom Bin Awang and Encik Mohd Shawal Faizal Bin Ismail who helped me a lot with the setup and fabrication of mechanical components. Furthermore, he also provided some advice on the support design of the stretcher so that I could complete the setup of this project on time. Special thanks to Mr Wan Mohd Amri Wan Mamat Ali, who guided me through some of my experimental works.

I would also like to give a special shoutout to Mr. Jeevinthiran a/l Karunagran who share a lot of his experience in designing a powered stretcher and gave me many good advice on what to look out for. His help had ensured the smooth ongoing of the project.

Apart from that, I am thankful to CERST for sponsoring this project financially. This dissertation could not have been possible without the needed resource to bring this project to completion.

Last but not least, I would like to thank all my family and friends who gave their help and moral support to me to keep me going throughout my life. They had put their faith in me through the highs and lows of this project and life in general. Thank you for all your encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

WMSD	Work-related Musculoskeletal disorder
CO/PES	50% cotton/50% polyester
PES	Polyester
PTFE	Polytetrafluoroethylene
COF	Coefficient of friction
ER	Emergency room
NIOSH	National Institute of Occupational Safety and Health
BEP	Bedridden elderly patient
RoNA	Robotic nursing assistant
RIBA	Robot for interactive body assistance
CAD	Computer-aided design
VSVO	Variable-step, variable order
DAE	Differential algebraic equations
NDF	Numerical differentiation formula
BDF	Backward differentiation formula
PU	Polyurethane

LIST OF APPENDICES

POWERED STRETCHER FOR PATIENT TRANSFER

ABSTRAK

Pemindahan sisi pesakit antara dua permukaan bersebelahan boleh menimbulkan risiko gangguan muskuloskeletal yang tinggi untuk jururawat dan pengendali pesakit. Disertasi ini membentangkan reka bentuk konsep sistem mekanikal yang dikhaskan untuk membantu kakitangan perubatan dalam mengendalikan dan memindahkan pesakit terlantar. Reka bentuk yang dipilih terdiri daripada tali sawat dan sistem roda mecanum yang berfungsi untuk mengambil dan menempatkan semula pesakit dan pada masa yang sama, tidak menyebabkan ketidakselesaan dan kecederaan. Salah satu objektif reka bentuk ini adalah untuk mengurangkan bilangan kakitangan perubatan kepada seorang sahaja serta menukar peranan orang tersebut daripada peserta aktif kepada penyelia operasi. Prototaip kasar telah dibina dengan sistem tali sawat yang berfungsi dan boleh membawa beban seberat 14 kg. Simulasi juga dijalankan untuk mencari daya sentuhan antara tali sawat dan pesakit semu dengan pelbagai julat kecondongan, kelajuan dan bahan tali sawat bagi pengusung perubatan. Keputusan simulasi menunjukkan bahawa daya sentuhan yang paling minimum dialami apabila sudut condong 7 darjah, tali sawat bergerak selaju 0.05m/s dan benang bulu sebagai permukaan bahan tali sawat. Terdapat banyak batasan dalam reka bentuk prototaip kerana projek ini merupakan langkah pertama dalam membangunkan dan meneroka penyelesaian reka bentuk yang boleh jaya dan senarai komponen sistem mekatronik yang diperlukan dalam melaksanakan pengangkutan dan pengubahan kedudukan pesakit terlantar.

POWERED STRETCHER FOR PATIENT TRANSFER

ABSTRACT

Patient lateral transfers between two adjacent surfaces could pose high musculoskeletal disorder risks for nurses and patient handlers. This dissertation presents the conceptual design of a mechanical system devoted to helping caregivers in handling and transferring bedridden patients. The chosen design comprises a conveyer belt and mecanum wheel system, which serve to retrieve and relocate the bedridden patient without causing discomfort and injuries. One of the objectives of this design is to reduce the number of medical personnel to only one and change their role from an active participant to that of an operational supervisor. A rough prototype was built with a functioning conveyer that could carry a 14 kg load. A simulation was also carried out to find the contact forces between the conveyer belt and dummy patient at varying inclination angles, speed, and belt material of the conveyer bed. The simulation results show that the least contact forces are experienced at an incline angle of 7-degree, conveyer speed of 0.05m/s and wool as belt material. There many limitations in the prototype design as this project represent the first step in developing and exploring viable design solutions and the list of components of a mechatronic system required in executing bedridden patient transport and repositioning.

Keyword:

Powered Patient Transfer Device, Conceptual Modelling, WMSDs, Mechatronic System

CHAPTER 1

INTRODUCTION

1.1 Research Background

The healthcare workforce's task includes stretcher and patient handling, predisposing them to work-related injuries [1]–[3]. Manual patient transfer via stretchers involves the medics physically raising and lowering the patient from one bed to another. Patients sent by the paramedic to the hospital is usually transferred onto an ER bed or operating table.

All these manual exertions are often pinpointed as the most physically demanding tasks of the medics' job that can cause work-related musculoskeletal disorder (WMSDs), typically back pain to the medical personnel[4]–[23] as proven by the prevalence rate that estimates 34.6 injuries per 100 health workers every year, the highest rate reported for any industry[2], [24]. Recent statistics identified that one of the seven jobs with the highest non-fatal injuries and illnesses reported in the US are the nursing assistants[25] and was recorded as an occupation of high exposure to overexertion injuries [26]–[29]. Over time, WMSDs developed to be a significant concern as injuries such as lower back pain evolves into a chronic disease that brings down the quality of work-life, and mental and physical health [10], [30]–[39], followed by the economic burden to the healthcare organizations [40]

A study revealed that the loads while lifting the manual stretcher often exceeded the recommended NIOSH limits [41], [42]. It is typically a 3-to-5-person task to lift and move a patient from a ward bed to a transfer gurney. This imposes a high risk of musculoskeletal complications on the nurses in the lower back region.

On the other hand, improvements in stretcher design has proven to lower the physical stresses inflicted on medics from related stretcher handling tasks to a minimal [8], [43]–[53]Therefore, amid the increasing demands related to stretcher handling associated activities, significant interest is invested in the emerging powered stretcher. This is because of the prospective benefits it could bring to the medical services in addressing the concerns associated with the conventional method. However, the current powered stretcher design cannot yet collect the patient from the ground without the lifting task being carried out by the emergency medical workers.

Hence, this project aims to design a stretcher that can semi-automatically carry out lateral patient transfer operations with minimum human intervention.

1.2 Problem Statement

Patient transfer is currently carried out by manually lifting the patient between the stretcher, ER bed and operating table, which can cause work-related musculoskeletal disorder (WMSDs) [4]–[8]. On the other hand, improvements in stretcher design had proven to reduce the physical stresses imposed [8], [21], [22], [35], [36], [43]–[48], [54], [55].

Amid the increasing demands associated with patient transfer-related activities, significant interest is invested in the powered stretcher and the prospective benefits in addressing the concerns related to the conventional method. Although patient transferring devices have been developed and commercialized, they are not widely used by healthcare facilities because of the lengthy and complex procedure of setting up the device. Moreover, some even claimed that some of the transfer devices do not reduce much of the physical burden of health workers. Therefore, this project aims to design a stretcher that can carry out such tasks with minimal personnel intervention.

1.3 Objectives

To provide a method of patient transfer with minimal physical exertion from the caregiver/nurse by achieving the following objectives:

1) To develop an automated stretcher that can transfer patients to the adjacent bed or stretcher
2) To design a stretcher that could move independently to transport a patient

1.4 Scope of research

In this project, the focus is on design analysis and fabrication testing of the powered stretcher. Firstly, the powered stretcher is designed to collect and transfer patients to and from a typical hospital bed. The system must be able to execute these actions without compromising comfort to the patient while at the same time able to reduce the caregiver´s effort. This is accomplished by analysing the requirements of a mechatronic system to accomplish said tasks and developing the corresponding solution. However, the project is limited to a conceptual prototype working with a weight less than an average patient. Full implementation onto a human is not yet planned due to the fund and time constraints of this project. Simulations are carried out to test the design's structural integrity and patient comfortability level during transfer operation. The powered stretcher was fabricated in the lab and workshop. The experiment would be carried out to ensure the good functionality of the conveyer and mecanum wheel.

CHAPTER 2

LITERATURE REVIEW

2.1 Issues with Conventional Patient Transfer

A bedridden person is vulnerable to various health complications such as fractures, bedsores and depression because of not moving for long periods. Thus, they are both physically and mentally strained. When a bedridden patient needs to relocate to another place for various requirements such as medical testing/operations, personal hygiene etc. Lifting and transferring patients in that condition is quite a difficult, challenging and risky task[56]. Bedridden patients undergo either assisted transfer where there is the active participation of the patient in the transfer with caregiver's assistance, or dependent transfer, where there is minimal involvement of the patient with the caregiver performing the whole transferring operation.

The ageing population and the reduction of young labour have become a huge dilemma for the healthcare system in hospitals [57]. Transfer of a bedridden patient from one flat surface to another, i.e. from a bed to a stretcher or laboratory/operating theatre bed, is one of the most common tasks during patient transportation in hospital [1], [58]–[62], that face challenges in work-related injuries, high work intensity, workforce shortage, and poor bed moving approaches. Generally, two workers are required to move a stretcher: one steers while the other pushes from behind. For patient transfer from one bed to another, two or more nurses have to insert their arms underneath the bedridden patient and drag them from one bed to the other targeted bed. Another technique requires three nurses to transfer a patient who cannot move alone from bed to stretcher by using a transfer board or slide sheet, as shown in Figure 2.1[39], [59], [60], [63], [64] to improve the hand grip interface and facilitate the transfer. With this technique, it is estimated that nurses exert a pull force up to 72.6% of the patient's weight. These operations cause tight and straining work schedules, and staff shortages will cause a delay in patient transportation operating room[20], [41], [65]–[68].

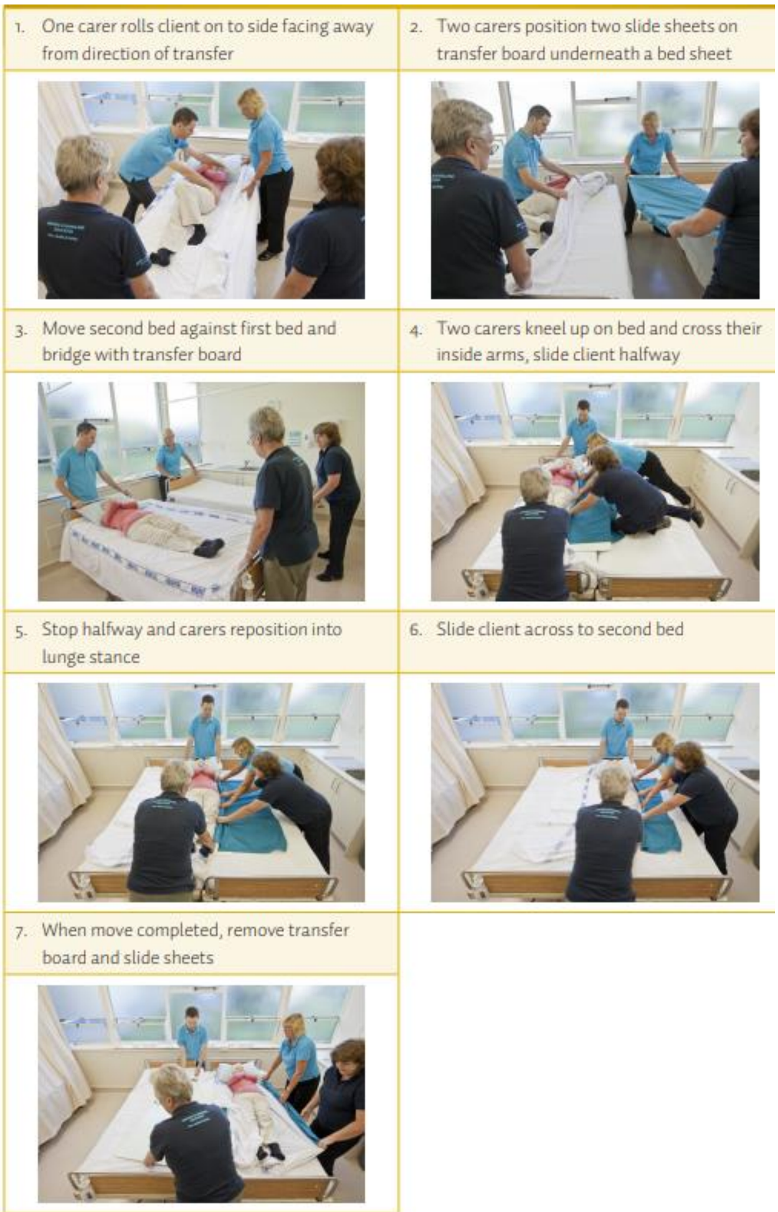


Figure 2.1 Lateral transfer using transfer board or slide sheets

Moving beds and repositioning bedridden patients are ranked as one of the most physically challenging tasks which could impose work-related injuries on the health care workers who has to exert more force to carefully transport a patient compared to transferring an equivalent heavy object to prevent injuries and accident[58], [69]. A patient does not have handles, nor do they have even weight distribution, which results in uncomfortable and unconventional postural stress[59], [64], [70]–[73].

There are instances when it is desirable to move patients from an intensive care unit (ICU) or examination room to a bed without altering their posture, which is especially so for post-surgery patients who might have several tubes and wires, post-anaesthesia patients, patients with fractured lower limbs or spinal injuries and post-dialysis patients. Handling bariatric patients only expose the hospital healthcare workers to more workload, higher strain on the back and orthopaedic injuries risk. Till now, the nursing profession continues to be the one with the highest injury rate[74], [75]. In such cases, nurses are recommended to use a mechanical lifting device or lateral transfer devices[58], [76]–[86]. Nevertheless, the medical staff are less inclined to use them because of needed time in locating and setting up the devices, social pressure to get the transfer done quickly, unavailable assistance, lack of perceived need for devices and inadequate training[87]–[89].

Repetitive bending and excessive lifting cause caregivers to sustain musculoskeletal injuries such as back pain which is the most frequent occurrence among nurses, with over 80 studies worldwide indicating an annual prevalence of 40% to 50% and lifetime generality of 80%[18], [58], [69], [75], [90]–[92]. These injuries affect the muscle tendons, nerves and bones, which, left untreated, may lead to WMSDs. It was claimed that this disorder had effectively brought upon an approximate economic loss of over 2 million working days and 13.1 billion USD[14], [91], [93]. WMSD could also prevent the nurses from continuing in this line of work.

Furthermore, the 2-D and 3-D static biomechanical models of patient handling have been explored, with results stating excessive compressive loads (typically L5/S1) during patient transfer even if two personnel are involved in patient lifting[31], [36], [38], [39], [69], [94]–[97]. It was also revealed that high compressive loads are imposed on the lumbar spine during patient lifting and repositioning operations [98]. In fact, dynamic analyses show that nearly all tasks involving patient lifting and repositioning exceed the limit for spine compression and shear tolerance even if the loads are relatively light weight (50kg)[99].

Many parties are invested in the development of patient transfer devices that could provide effortless assistance in patient handling tasks, including repositioning and transferring bedridden patients[100].

2.1 Current Powered Stretcher Design

Since the late 18th and early 19th centuries, patient-transferring devices have been studied. The clinical need for patient transfer devices is steadily growing with the ageing of the population. The intelligence level of these devices has been consistently upgraded together with the exponential progression in computer technology. Simple patient transfer devices have evolved into smart robots. Patient transfer devices are classified into two categories based on how they move patients: lift-sliding type and horizontal moving type.

The main aspect of lift-sliding type transfer devices is that the patient who is lying on the hospital bed or operation bed is first hoisted up by raising the carrying arm. Then, the patient is transferred to the transfer bed before being placed on the bed by dropping the carrying arm. Most lift sliding devices need ergonomic assessment and modification of spaces where transfers take place since the device usually take up a lot of room[89], [101]–[103].

Jiang et al. [104] proposed a patient transferring robot. The carrying arm is driven by the first screw nut mechanism, while the arm is driven by the scissor system, powered by the second screw nut mechanism. The patient can be transferred to the hospital through the synchronization of the first and second screw nut. The advantage of this design is that the original posture of the patient can be well maintained since vibration in transferring operation is small. But the cantilevered structure is too large to maintain the load capacity, and this device is not easy to be operated in narrow rooms.

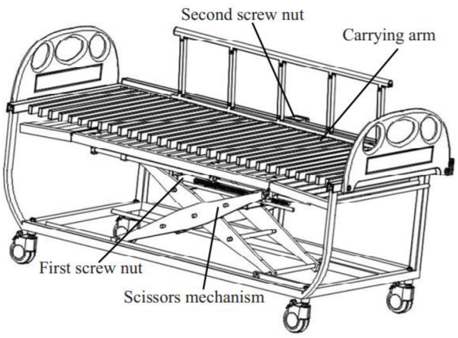


Figure 2.2 A patient transferring device CN104921877

Xu et al. [105] designed a portable apparatus that involves a lifting mechanism and a grabbing mechanism. The lifting mechanism is done by turbine and worm system. The grabbing mechanism involved a mechanical hand grasping. The end of the arm is usually attached to a sliding guide to transfer a patient between beds. The design structure is simple and space-saving. However, the grasping lifting height needs to be calibrated individually during the transfer since the design has poor consistency. There is also a need to attach a sliding guide for the bed.

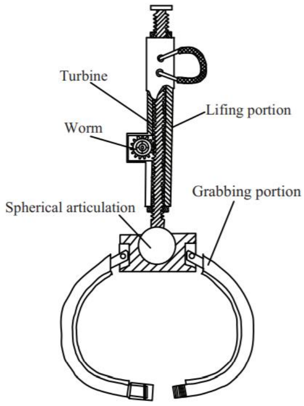
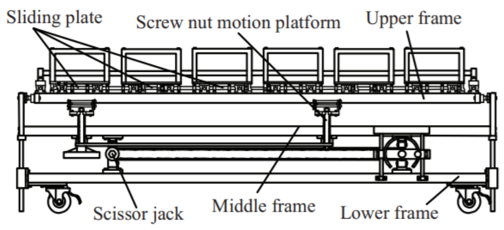
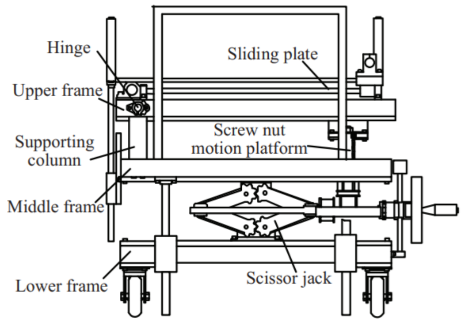


Figure 2.3 A portable patient transferring apparatus CN205083885

Tian et al. [106] developed a mechanical transferring device that is composed of three frames: upper, middle, and lower. The scissor jack's mechanism is employed for height adjustment in accordance with the hospital or operating bed. The sliding plate is placed underneath the patient, where one side of the plate must be held. The nut screw motion will lift the patient without letting the patient slip down. Lastly, the patient is placed back on the sliding plate. The sliding is divided into several parts to make it easier to transfer the patient. Nevertheless, the device can only execute the unilateral transfer.



(a)



(b)

Figure 2.4 A mechanical patient transferring vehicle CN103494677: (a) Frontal view and (b) Lateral view

A patient transferring device [107] involves the inflatable air mattress and fixedly attached sling sheet. During the transfer operation, the sling sheet could be loosened to carry the patient to the transferring bed. At the same time, Robert et al. [108] designed an apparatus that has an inflatable mattress that has plenty of fasteners to attach the mattress so the patient can be transferred together with it. The design has a low degree of automation. Moreover, additional gas sources are needed for these devices. This approach was similarly used by several other researchers[109]–[112].

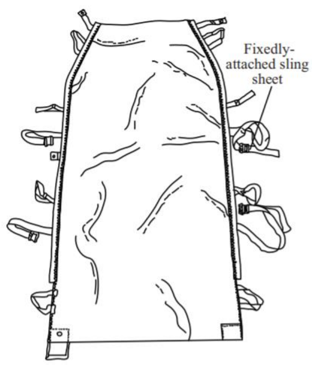
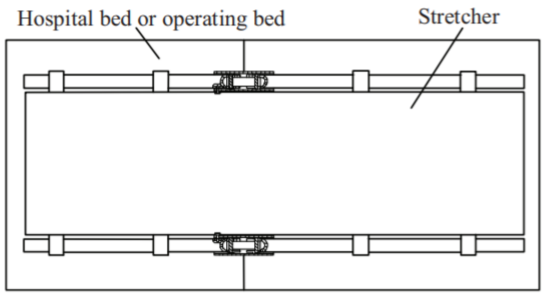
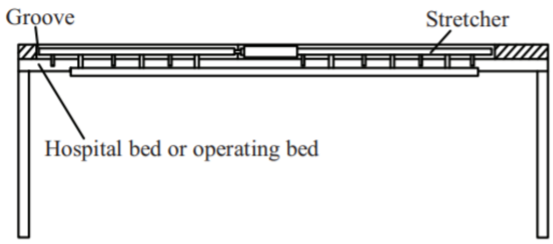


Figure 2.5 Patient transferring device with inflatable air mattress and fixedly attached sling sheet WO2015179748.

A stretcher hidden care bed is developed [113]. The hospital or operating bed is set with grooves to embed a carrying arm which is placed with the stretcher. A mechanism similar to the sunroof opening is applied in the carrying arm to lift the patient up and carry them aside to the target bed. Although the design has a sophisticated lifting-sliding mode, the arm that needs to be mounted on top of beds makes this design difficult to popularize. In addition, the nurse had to carry the stretcher since the automation level was low.



(a)



(b)

Figure 2.6 Stretcher with a hidden care bed CN201759773 :(a)Top view and (b) Frontal view.

Cai et al. [114] designed a surgical cart that has two main movement joints that move the carrying arm. The movement is hydraulic-powered, and a balancing bracket is installed to balance the cart. The patent only creates small vibration and provide simple control. The design is, however, too complex as it involves many hydraulic mechanisms.

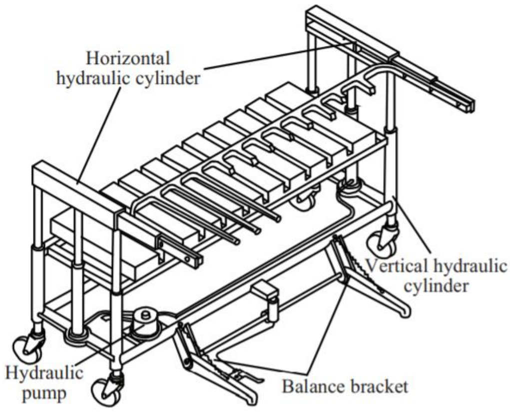


Figure 2.7 A surgical cart CN2691545

Yan et al. [115]developed a device that consists of a column, a boom and a hand gripper. The column is attached to the end or head of the device's bed, while the boom is connected to the gripper through rope and is mounted to the column. A rack and pinion at the upper portion of the column to transfer the patient from this movement with the boom. At the same time, Zhang et al. [116]proposed a medical electric trolley that is L-shaped and integrated with a hand gripper. Two foxed pullies are mounted to the L-bracket through the rope. Although functional, drawbacks can be observed from the rope connection between the griper and boom since it increases the patient's vulnerability to vibration. The device also occupies a lot of space, thereby not easy to popularize.

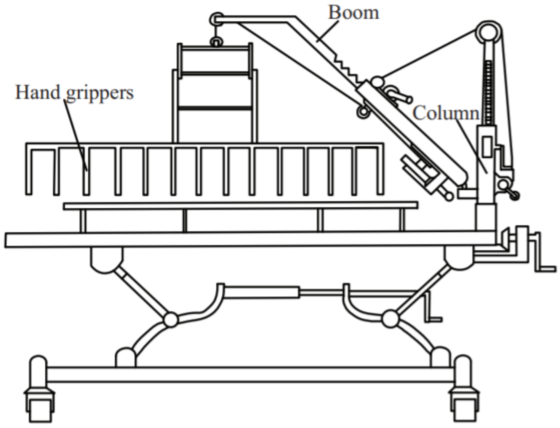


Figure 2.8 A medical bed type patient transferring device CN2527264

Heather C. Humphreys et al. [117] fabricated a four-degree freedom device powered by an electro-hydraulic actuator (EHA). The lifting method is also referred to by several other researchers [118]–[123] and was comparatively reviewed by [37], [124]–[126]. The boom's end has a hanger bar that is attached to a sling in which patients rest. The boom is driven by a belt drive mechanism and is actuated via a low-speed high torque hydraulic motor. The patient lifting involves a hydraulic-powered scissor system. The device requires lesser forces from the operator, moves with its own powered base, is faster and has a larger range of motion compared to other lift devices. Disadvantages include lacking smoothness of the base control with a low power unit. The speed of the lifting response is lower than desired. The mechanism is best operated at the presence of two caregivers. This is due to the devices not possessing any sort of safety net underneath so that any blunder can cause severe damage to the person being lifted.