Universidade do Minho
Escola de Engenharia

Bruno Manuel Fernandes da Silva

Design of mechatronic system for handling bedridden People

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Dissertação de Mestrado
Mestrado em Engenharia Mecatrónica

Trabalho efectuado sob a orientação do
Prof. José Mendes Machado
Prof. Nuno Ricardo Maia Peixinho

dezembro de 2015

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"Nothing in the world can take the place of persistence.

Talent will not; nothing is more common than unsuccessful men with talent.

Genius will not; unrewarded genius is almost a proverb.

Education will not; the world is full of educated derelicts.

Persistence and determination alone are omnipotent."

Calvin Coolidge

Title

Dimensioning of mechatronic system for handling bedridden people.

Abstract

This dissertation presents the conceptual design of a mechanical system especially devoted to assist caregivers in the handling and repositioning of BEP. The chosen design consists of a conveyor belt like structure, which extends from a base unit, which is able by means of its belt element to retrieve and relocate the BEP without causing discomfort or lesions. One of the objectives of this design is to reduce the number of caregivers to only one element and change his role from active participant to that of an operational supervisor. Another objective is to reduce the system's handling complexity since most of the time the system will be used by an aged person. Some visits to rehabilitation centers and hospitals were performed, in the context of this work. This aspect was essential for developing a very adequate equipment for the main purposes specified at the beginning.

This dissertation provides a framework to the development of AAL systems that aim to handle and move bedridden elderly persons exposing the requirements and challenges involved. The resulting framework in junction with biomechanics data and conditions regarding BEP's living environment result in the required specification for this design. The resulting work, of this dissertation, produced a viable design solution and required components of a mechatronic system that can handle the movement and reposition o bedridden individuals.

Keywords:

Ambient Assisted Living, Conceptual Modelling, Mechatronic System, Bedridden Elderly People, Wellbeing

Título

Dimensionamento do sistema mecatrónico para mover e reposicionar pessoas acamadas.

Resumo

Esta dissertação apresenta o design conceptual de um sistema mecânico especialmente dedicado a auxiliar cuidadores para manusear e reposicionar de pessoas idosas acamadas. O design escolhido consiste numa estrutura provida de uma correia transportadora que se estende a partir de uma unidade de base e que é capaz por meio do seu elemento de rolante de recolher e depositar o individuo acamando sem lhe causar desconforto ou lesões. Um dos objetivos deste sistema consiste em reduzir o número de cuidadores para apenas um elemento e alterar a sua função de um participante ativo para o papel de um supervisor operacional. Outro objetivo é reduzir a complexidade de uso do sistema uma vez que a maior parte do tempo o sistema será usado por uma pessoa de idade. Foram realizadas algumas visitas a centros de reabilitação e hospitais, no contexto deste trabalho. Este aspeto foi essencial para o desenvolvimento de um equipamento adequado para fins especificados.

Esta dissertação fornece um enquadramento para o desenvolvimento de sistemas de AAL que visa mover e reposicionar pessoas idosos e acamados expondo as exigências e os desafios envolvidos. Este enquadramento em junção com os dados biomecânicos do ser humano e requisitos no que diz respeito ao meio onde a pessoa acamada reside resultaram nas especificações para este design. O trabalho resultante, desta dissertação, produziu uma solução de design viável e respetiva configuração de decomponentes necessários para a criação de um sistema mecatrónico que pode lidar com o movimentação e reposição de indivíduos acamados.

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This desertion could not have been possible without the help and encouragement of several people. First and foremost, I thank my academic advisor, Professor José Machado for introducing me to the subject of my dissertation and bringing me into his wonderful workgroup were I met professors, Filomena Soares, Vitor Carvalho, Demétrio Matos and Nuno Peixinho. Under their guidance, I was intellectually challenged, given a place to share and discuss new ideas and was given creative freedom to accomplish my goals.

Through this team, I also met and collaborated with several other student colleagues from diverse areas of study and hope that we have all matured and learned from each other. I would also like to acknowledge the contribution of the colleagues that worked alongside me in the mechatronics laboratory. Some of these individuals started as colleagues but by the end of this work matured into friends.

My academic path could not have come to fruition without the love and support of my parents Antonio and Maria, my brother Ricardo and my life partner Vera. To all, my gratitude is beyond expression. I will never be able to fully thank you enough.

Index

Acronyms

AAL	Ambient Assisted Living
ADL	Activities of daily living
AT	Assistive Technology
BEP	Bedridden elderly people
CAD	Computer Aided Design
ECS	Environmental control systems
FSR	Force Sensing Resistor
IT	Information Technology
LEDC	Less economically developed country
MEDC	More economically developed country
PLC	Programmable Logic Controller
SCAIP	Social Care Alarm Internet Protocol
SDK	Software Development Kit
TPE	Thermoplastic elastomers
UI	User Interface

Units

Designation	Symbol	Unit
Acceleration	a	$\mathrm{m/s^2}$
Acceleration due to gravity	g	$\mathrm{m/s^2}$
Angular velocity	ω	$\mathrm{rad/s}$
Arc of contact on driving pulley	β	rad
Axial Load	F_a	N
Coefficient of static friction between belt and pulley	μ_s	-
Effective pull	F_u	N
Electric current	I	A
Electric current	V	-
Electric Resistance	R	Ω
Euler's constant	e	-
Friction coefficient	μ	-
Frictional force	F_r	N
Lead	l	m
Mass	m	kg
Normal efficiency	η	-
speed	v	$\mathrm{m/s}$
Temperature	T	C
Tensile force in the slack side	F_2	N
Tensile force in the tight side	F_1	N
Time	t	s
Torque	T	Nm
Voltage In	V_{out}	V
Voltage Out	V_{out}	V
Wrap angle	β	deg

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Chapter 1

Introduction

This introductory chapter aims to present the content of this work by making a brief introduction to the topic as well as establish the motivation behind this work. Objectives are presented in clear and concise manner and the chapter ends by describing the adopted structure by indicating the information contained in each chapter.

Severe demographic changes are bringing new challenges to developed countries. When we look into statistical studies of populations in more economically developed countries (MEDC) we denote a significant decrease in birth and death rates values in conjuncture with an increase in life expectancy. During the twentieth century, we observed a reduction in fertility rates. The average fertility rate, from 1950 to 1955, was 2.8 children per woman in the MEDC but has since been declining. From the start of the new millennia to the year 2005, the average value dropped significantly to 1.5 children per woman. This means that total fertility rate is lower than the replacement level. Currently in 19 of the MEDC, a fertile couple is bearing in average 1.3 children. The ageing population phenomenon is a global problem and it present itself as one of the major social issues that current governments must face. Although genetics play a big part in life expectancy are in the surroundings in which one grows in resides that most effects this value. High life expectancy is greatly influences by improved public safety, healthcare resources (such as medicine), nutrition and housing. In Figure 1 we can see how drastic the regional variation of life expectancy is. Further analysis shows how longer life expectancy is directly correlated to the fact that most of these countries are considered MEDC.

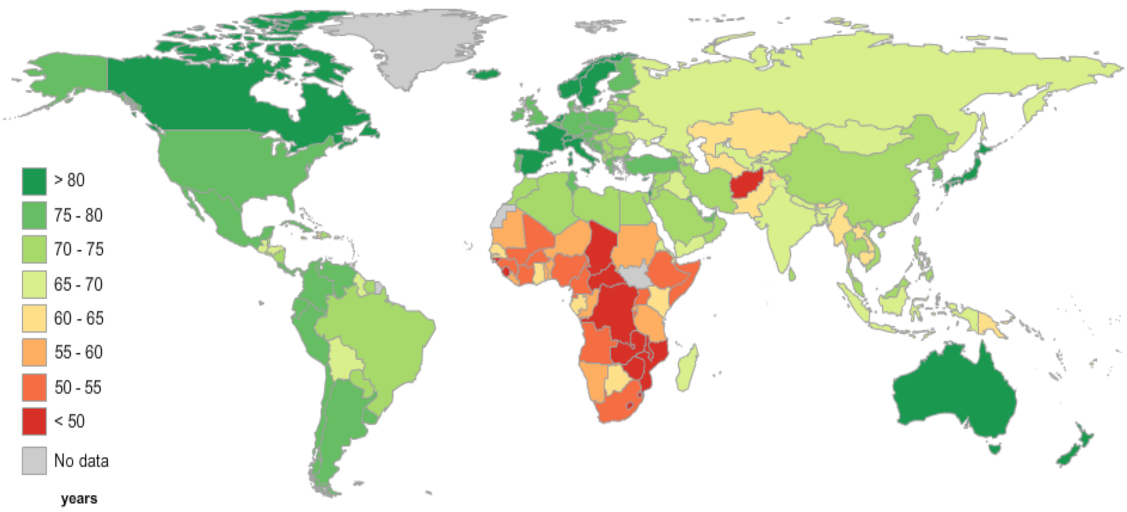


Figure 1 - Life expectancy at birth, totals 2009 [1].

Japan, currently the country with the higher life expectancy, is facing severe socio-economic pressures due to its aging and shrinking population. In 2005, Japan elderly population (persons aged 65 and above) corresponded to 21% of its entire population and will correspond to

25% by the year 2020. The Japanese household size has also diminish over time from five persons in 1950, 2.7 persons in 2000 and 2.58 in 2005. This means less caregivers in the household to provide care so more nurses must undergo specialized education and training in geriatric healthcare. Asking more people to work in this sector is shrinking an already reduced working population. Nevertheless, Japan is often referred as an example to fallow regarding its enormous success in managing care for its ageing population. This success is highly due to governmental entities issuing several legislation such as the welfare law for the elderly and measures such as the public long-term care insurance plan. In addition, campaigns to indorse further advances in medical care, construction of healthcare infrastructures, and development of community services as well as promotion of social participation are always present in the governmental policies. Great advances have been made regarding new treatments, procedures, and products for various forms of healthcare [1]. Comprehending that technology will greatly influence the future of healthcare both the government and private sector have invested large amount of resources to further advances medical technology. Robotics applied to healthcare is an area being especially well received do to Japanese culture greatly embracing the concept of robot helpers [2].

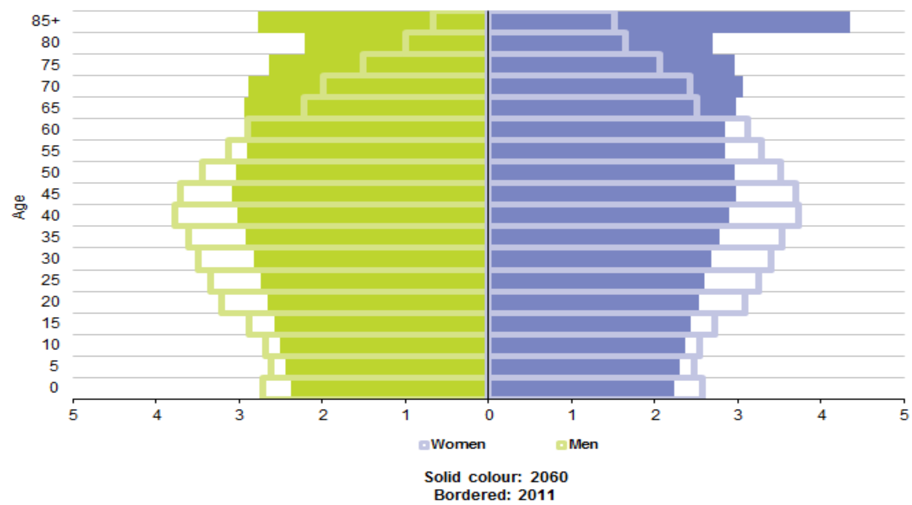


Figure 2 - European demographic data [3].

By 1980 in the European continent, the United Kingdom, France, Italy, and Germany already had surpassed the elderly population level that we see at the present in the United States. The European Commission Directorate General Health & Consumers is projecting gradual growth in the life expectancy rate in the EU. By 2025, elderly European people will represent 20% of its entire population. If this trend continues, we will see a surge in the number of people over 80 years along the next fifty years. This factor in association with the low levels of fertility that have persisted for decades in the EU is the most relevant contributing to the ageing of the EU-28's population [3]. Shown in Figure 2 are current and projected demographics data for Europe [4]. The population of the United States is aging more slowly than other MEDC. Between 1980 and 2010, the rate on growth of the elderly population only corresponded to 2% of the U.S. population but in the same period, Japans elderly population grew at seven times this rate. However, since 2010 the rate at which the U.S. population is aging as increased. This is also true for other MEDC such has Russia, U.K., France, Italy, and Germany. As presented in Figure 3, projections indicate that by 2050 approximately 89 million adults will be aged 65 or above and 25% of these individuals will be over 85 [5].

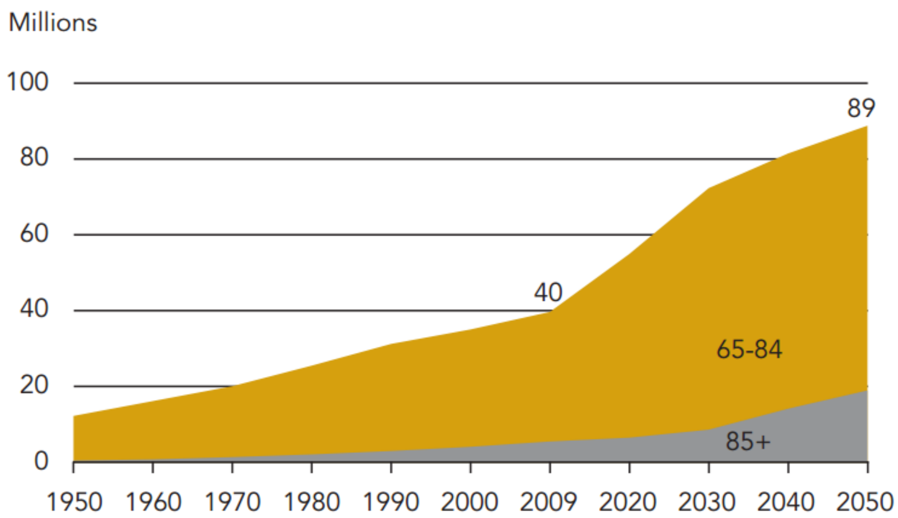


Figure 3 - U.S. Population Ages 65 and Older, 1950 to 2050 [5].

As exposed accelerated aging and declines in fertility are socioeconomically issues affecting most of the MEDC. Nevertheless, what is striking to observe from demographic studies is that less economically developed country (LEDC) are facing similar issues countries such as India, Mexico, Brazil, and China. The world elderly population represent currently one tenth of the world population. Projection estimate that this will increase to one fifth by 2050 this number represents around 1500 million people [6]. With this panorama, difficulties associated with these issues are unavoidable. Such as, granting a vacancy in an elderly healthcare institution for all these individuals is impractical and undesirable. In addition, when the number of bedridden elderly people (BEP), which no longer possesses the autonomy and ability to care for themselves increases, the need for capable people to provide care will also increase. These caregivers may be divided in two categories, professional's caregivers or non-trained individuals. Professional caregivers can be found in healthcare institutions such as hospitals, adult day care center, nursing homes and hospice but also in the home setting as private caregivers. Non-trained caregivers are individuals that may be part of the household or employed to take care of the elderly person but have never undergone professional training. The dangers and difficulties of this line of work are similar in both cases. Case in point, in all the settings missioned above caregivers, professional or not, and bedridden individual are prone to musculoskeletal injuries. These types of injuries may reduce or even disable the ability for the caregiver to provide further care. For the bedridden individuals these injuries signify more discomfort, less mobility, pain and an overall decrease in quality of life. In the case of caregivers that are part the household, usually the life partner, aged and with physical limitations may condition the quality of care that is provided to the BEP. Do to the factors indicated above many entities are interested in the development of devices to provide effortless assistance in all aspects of BEP care, including repositioning and transferring BEP's. A tool, for satisfying this specific aspect, or others, on the same context would be well embrace by this sector and highly appreciated by those that need it.

1.1 Motivation

Presently available solutions to provide support to movement and repositioning of the elderly possesses several deficiencies and shortcomings. In the case of presently available home equipment's solutions are, in most cases, a strip down, less sturdy and costly version of the hospital model. These devices usually only fulfil one purpose and it is necessary to combine the features of several of them with physical aid from a caregiver in order to move or reposition bedridden individuals. Although many public and private organizations are aware of these issues, the development of better applications are not meeting the need. The main motivation behind this work is to develop a mechanism for BEP to reacquire some autonomy of movement and thus improve their quality of life without intruding in their privacy or compromising their dignity. This dissertation aims to provide a better solution, in one or more aspects, to the movement and reposition issue by combining different types of technologies and interdisciplinary knowledge.

1.2 Objectives

The desired goal is to create one (or more) solution(s) that not only facilitates the daily routine of the BEP but also provide a more comfortable and harmonious life for all elements in the household. The BEP's daily routine is comprised of several diverse tasks, which require an Aid to Daily Living (ADL). This work will discuss the development of a mechatronic system solution to adjust the BEP's body position in bed, transport between locations in the household and be a transference platform between devices (bed, wheelchair, etc.). The system must be able to execute these actions without compromising comfort to the BEP and reducing the caregiver´s effort. Although, the solution developed is primarily intended for the home setting it desirable that it could be adapted to the healthcare industry. This is accomplished by analyzing the requirements of a mechatronic system to accomplish said tasks and developing the corresponding solution.

1.3 Structure

This dissertation is structured in an arrangement of seven chapters so distributed in order to provide a clear train of thought to the subject matter. Chapter 2 sets the framework to this work by providing a more detailed explanation of the target group; actors involved and developed work in this field. Chapters 3 addresses the physical attributes, such as weight, height and volume, of the human body that influences the device to be developed. Over the course of this work, several other have been explored in order to accomplish the outlined objectives In Chapters 4, those mechanisms are listed with a detailed description as how they operate as well as a justification as why further development was not pursued. The fifth chapter shows the adopted solution that resulted from a new approach and the experience gained through previous designs. An explanation of how this solution functions is described in further detail. Chapter 6 elaborates on chapter 5 by listing the key components that are part of this solution. Each component is defined as what they are and what function they provide to the overall solution. When applicable, the components description will also include their selected process. The seventh and final chapter presents a general conclusion to the dissertation, as well as guidelines for the future work that might be developed.

What to retain from chapter 1

The increase in life expectancy of elderly people in conjunction with a decline in numbers of the younger population is leading to a shift in demographics. Both MEDC and LEDC are being affect by this issue becoming a global occurrence. The social changes that this issue brings have a great impact the care that is provided to the elderly population. This demographic trend will be accompanied by an increase of people that possess physical limitations and therefor no longer have the autonomy of movement and ability to take care of themselves. This also means that the ratio between caregiver and elderly person will widen. The development of better solutions and techniques to help caregivers provide care to the elderly is desperately needed if we hope to cope with these changes in demographics.

Chapter 2

Framework

This chapter aims to provide a detailed description of the actors involved in the subject of elderly care as well as provides in further detail a definition of bedridden elderly person and their needs. Provided also is a description of the currently available commercial solutions as well as what is being developed in this field and relevant standards to this subject.

The saying “it takes a village to raise a child” is a traditional African proverb that can also be applied to the elderly. It must be understood that elderly care is an issue that concerns more than just the elderly person. In fact, this directly concerns and affects the elderly love ones and extends to the convention of a social responsibility, enforced by laws, which we as a society have established. The elderly should not be seen as a burden but as individuals whom contributed to the development of society to which they belong and as such should be honored with support when they require care in their golden years [7]. An elderly person is defined as an individual with an age of 65 or above that begin to undergo a deterioration of their capability of movement and health. However, this parameterization is only a convention employed, among others, by sociologists, demographers, anthropologists and researchers in order to better define a set of individuals. This convention is not always suitable since many of individuals that fall into this category are still very active members of society, sometimes with jobs, and have not yet shown any signs of decay in their capability’s. In addition, the increase in life expectancy and life quality will soon change our definition of what defines an elderly person. The aging process is something very personal and is influenced by many aspects such as biological, nutritional, environmental and lifestyle choices.

2.1 Bedridden Elderly Person

This convention is adopted due to the consensus that this is the age were most individuals start to show issues related to old age. In some cases, the state of the deterioration of an individual's health is such that he becomes bedridden. Losses in mobility and other activities related to autonomy and independence are denoted and thus the BEP is unable to execute his activities of daily living (ADL). In these cases, a home health aide is required. Usually this person provides assistances to the BEP with his ADL’s and or IADL’s.

2.1.1 Daily living activities and instrumental activities of daily living

Activities of daily living (ADL) are basic activities that are necessary for a self-care from an individual. The ability to feed oneself without assistance is an ADL, this ability does not comprise meals preparation or even the body’s ability to process said meal. Body hygiene such as bathing/showering, personal hygiene and grooming are also ADL’s. Mobility is another ability that is synonym with independence while mobile an individual is not restrained to a specific locations and this facilitates the execution of other tasks. These activities of daily living are considered activities that one needs to be able to execute by oneself not to be confused with instrumental activities of daily living (IADLs) fundamental functions, one must possess to live autonomously deprived of additional support from others. These activities include, among others, the ability to acquire consumer goods, food preparation, managing finances, use of electronic communication devices, manage medical prescription consumption and mobility within the community. The application to be develop in this work is intended for bedridden elderly people (BEP) but may also be applied any other injured or handicapped bedridden adult individual. The developed solution purpose is to aid the bedridden individual or its caregiver with ADL's more specifically in the case this work the persons transport and transference.

2.1.2 **Health concerns wen handling an bedridden elderly person**

As most elderly persons these bedridden individual suffer from one or more types of physical and/or cognitive feebleness. Therefore, some cautionary measures must be undertaken in order to minimize or eliminate the risk of further injuries or decline of health from the BEP. One of the main concerns when dealing with these individuals is skin care since hits the first defense that the human body possess against outside threats. This protective barrier repels contaminants such as toxins and bacteria that causes infections. The skin is also able to absorb or dispel some radiation such as ultraviolet-light and temperature, but this ability is limited and wen the threshold is exceeded injuries become noticeable. The skin is provided with a comprehensive warning mechanism that alerts to pain stimuli by means of pain receptors composed of nerve endings [8].

Figure 4 - Pressure ulcer on an elderly person (adapted from [9])

These enable the individual to perceive discomfort or pain and thus address the cause of the problem preventing further damage. For bedridden people one of the major source of distress are skin lesion such as pressure ulcers shown in Figure 4, also known as pressure sores, bedsores and decubitus ulcers, and are an unavoidable subject when talking about BEP. Pressure ulcers occur when constant pressure is applied over time on a localize area of the skin creating injuries that spread and fester translating into a source of pain and discomfort.

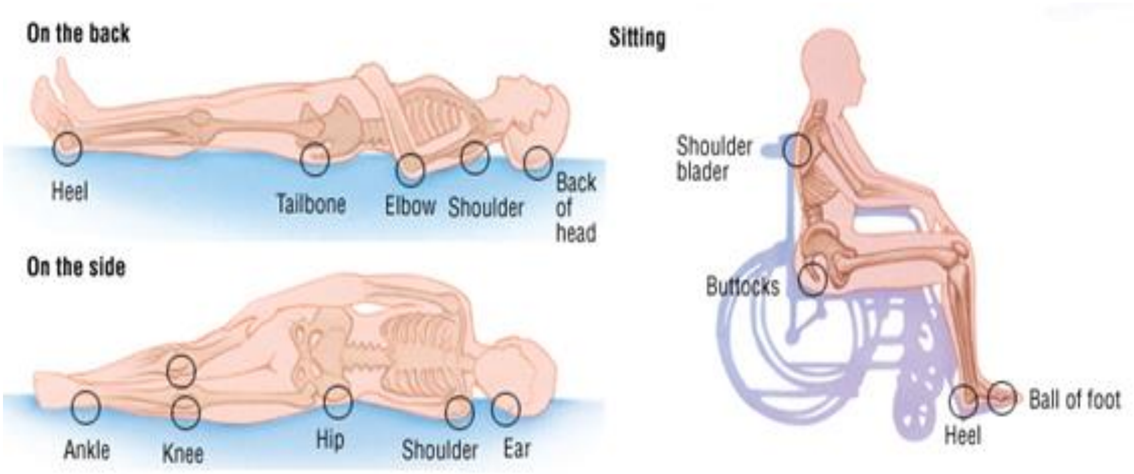


Figure 5 - Locations where pressure ulcers most commonly occur (adapted from [10])

The burned of pressure ulcers is estimated to cost the United Kingdom health care system 4 billion dollars every year [11]. The areas most prone to be affected by pressure ulcers are shown in Figure 5. It should be noted that these locations coincide with the pressure points created by the mass of the body depending in which rest position the person is placed. These points of constant pressure are also denominated points of sustained mechanical tissue loading. In order to avoid these injuries, skin contact with a given surface should be relieved as much as possible and changes to the position in which the individual is disposed will help towards minimizing discomfort and preventing sore development. The elderly skin elasticity is also affected, the skin no longer possess the ability to withstand deformation so any friction between the skin and a surface may cause discomfort or even scaring the skin wen force or movement is applied. In addition to these issues, many of these individuals are prone to joint pain and rapid or unusual movements may cause severe or irreparable damages. Therefore, transport, transfer and repositioning of the elderly must be performed gently to prevent discomfort or injuries [12]. This is especially true when performing the BEP hygiene routine since in order to perform these actions on areas of the skin that may be affected by lesions or irritation force and contact must be applied.

Temperature Control is another issue that greatly affects the elderly since these individuals have difficulty regulating their body temperature. The fact that most of these individuals suffer from some sort of blood circulation problem increases the difficulty of the body to perform thermoregulation. When these individuals are unable to maintain their normal core temperature the likelihood of a disease related to this deficiency may appear and medical emergencies related to this problems may transpire. Hypothermia is one of these issues, it occurs when the individual's core body temperature drops below 35 degrees Celsius and can lead to disorientation, hallucination, involuntary muscle contractions, irregular heart rate and ultimately results in death. The elderly body possess a slow responses wen reacting to temperatures changes. Their ability to shivering and perform vasoconstriction of the blood vessels is greatly reduced. Even if the problem promptly detected, the elderly body's takes longer to regulate the core temperature to normal values. Hypothermia can be prevented by avoiding the consumption of products that alter the heart rate such as alcohol and caffeine. Remaining in temperature controlled room, avoiding taking cool baths or showers and reduce the effort and strain on the body greatly reduces the chance of risk. Similar measure can be taken to avoid also other medical emergencies such as hyperthermia. Normal body temperature ranges from 36.5 to 37.5 degrees Celsius hyperthermia occurs after this range and is the result of the body overheating. Body core temperatures above 40 degrees Celsius can be fatal if not treated. As referred earlier the elderly have difficulties regulating and responding to temperatures changes. They also possess a reduced capability to detect dehydration and the blood vessels ability dilate is diminished which greatly impairs the bodies ability to cool itself.

2.2 Caregiver

Bedridden elderly people always possess some type of impairment; physical and/or cognitive, so in order to assist these individuals with their ADL's support from third party is required. These assistants can be denominated as caregivers or cares and can be of relation to the BEP, a paid informal caregiver or a paid/unpaid more formal type of assistant. The role of caregivers have changed alongside demographics changes. Caregivers are tasked to support the BEP with ADL's and/or IADL's depending on the level of care required. These tasks may include, but are not limited, to one or several of the tasks found in Table 1.

Table 1 - Caregiver assistance with ADL's and IADL's

Bed hygiene:	– Interchange sheets; – Clean bed; – Interchange hygiene equipment (such as underpads).

Daily personal hygiene:	– Body hygiene (Bathing and showering) & mild cleaning; – Personal hygiene and grooming; – Assist in dressing the BEP.
Comfort:	– Adjust the BEP body position; – Temperature control;
Transport or transfer:	– Transport the BEP from one location onto another; – Transfer between the bed and other devices;
Diet:	– Prepare daily meals; – Supervise diet;
Health	– Biometric data acquisition; – Medical consultation/emergencies; – Medication Management (Monitoring and Review)

What is to be expected from professionals or informal caregiver is changing as well and continues to change to meet the needs and demands of today's demand. The elderly prefer to stay in their homes but the need for a caregiver is still present so many organizations have implemented forms of assistance. Be them either paid or unpaid these organization require that their caregivers be trained and certified to do so [13], [14].

2.2.1 **Professional caregiver: The gerontological nurse**

Geriatric medicine is a specialty that focus on the health needs and conditions of the elderly. Treatment are formulated to respond to limitations, disabilities and diseases to the specific conditions found in individuals with a more advance age. Geriatrics subspecialties covers almost all the same subspecialties that are found in regular medicine intended for um adult but they differ in diagnose and treatment. Although all subspecialties are necessary to improve quality of life of the elderly in the focus of this work special attentions will be provided to gerontological nurses specialized in geriatric nursing. These individuals are not to be confused with other healthcare technicians like nurses or assistant nurses since they provide a specialized type of care do to their specialized skill set. These professional and certified individuals are dimed qualified to handle the BEP ADL's and IADL's. Certifications come from the completion of training and examination on ability's and knowledge required of gerontological nurses. These requirements are determined by each countries health systems and social services and enforced by their legislations. Most of these trained professionals caregivers are associated to some sort of private or public assisted living institutions. Each country possess different networks of healthcare services for the elderly. These can be comprised of any arrangement of hospitals, long-term care facility, residential care services, assisted living facility among many others. The need for such services is what dictates this arrangement and their number. As seen earlier these needs will soon change alongside demographic changes.

2.2.2 **Informal caregiver**

When assisted living institutions are unable or unavailable to offer assistance, care is usually provided to the elderly in their residence by an informal caregiver that do not possess training in elderly care. These can be individuals that provide assistance in exchange for monetary compensation or an individual who is part of the household. The second type of informal caregiver is more common since the incumbency of taking care of the elderly generally falls upon the family. In most cases, this task falls upon the BEP's life partner. These caregivers have approximately the same age as the BEP and hat that age they possess reduced strength and stamina, attributes required to properly handle the infirm. After long-term care, physical and psychological health decay may be observed on both parties. Despite these difficulties the majority of elderly people prefer to remain in their own homes for as long as possible. This is highly due to the familiarity of their surroundings and the socials stigma that is associated to an elderly individuals been sent to live in an assisted living institutions dreading the loss of privacy and choice autonomy [15]. In addition, the manner in which care is provided in the household differs greatly form other locals since the affection that transpires from the caregiver (spouse or other family member) significantly affects the care that is provided to the BEP [16].

2.2.3 **Manual movement or repositioning of patients**

Shown in this section is the amount of effort and expertise required from caregivers in order to move or reposition the bedridden person. The techniques shown are procedures that professional caregivers are instructed and trained to perform. The procedures either require additional specialize equipment and/or for a second caregiver to assist in the execution of the technique [17].

Figure 6 – Caregiver use of transfer sling to transfer of BEP from bed onto wheelchair (adapted from [17]).

The procedure in Figure 6 shows the transfer of the patient from the bed onto a wheelchair. This procedures requires the use of a transfer sling (applied around the waist) or gait belt (applied around the waist and between the thighs). This device helps the caregiver to distribute the force applied to the patients and at the same time provide a better grip. Denote the stance of the caregiver in the left image, the caregiver must use his legs to elevate the patient. Afterwards the caregiver must rotate the patient on is axis and carefully deposit him in the wheelchair. This rotation can be help through the use of a transfer pivot disc on which the patient stands and rotates. The transfer of the patient from a wheelchair on to a toilet is the reverse process of transferring the patient from the bed onto wheelchair.

Figure 7 - Caregiver use of transfer board to transfer of BEP from bed onto wheelchair (adapted from [17]).

Transfer of the patient from the bed onto a wheelchair can be done with what is called a transfer board. As seen in Figure 7 this board is positioned underneath the patient and is used as a sled to drag the patient. With a rigid transfer board, the caregiver must tilt the board to deposit the patient onto the wheelchair. With a flexible board, the patient is dragged onto the wheelchair and then the caregiver removes the board. Both devices must be lock in position so that they do not move during the procedures. Due to several elements here described, these procedures are highly prone to accidents.

Figure 8 - Caregivers transfer patient from bed to stretcher (adapted from [17]).

The transfer processes of a patient from bed to bed or bed to stretcher are similar. One technique requires two or more caregivers to insert their arms undneath the patient and drag him from one device onto another. Shown in Figure 8 is another technique that requires three caregivers that also put their arms underneath the patient lifts him from the device origin and deposit him on the target device. Both these techniques require more than one caregiver but there is another technique that a single caregiver can apply by using a sheet from the bed on which the patient is already laying and drag it on the other device [17]. Professional caregivers perform these techniques with the intent of reducing the strain on their patients. They sometimes require more than one caregiver or the use of specialized equipment to be performed. Caregivers that work in healthcare institutions assist several patients during their workday, even with these methods, the amount of physical and psychological stress that they suffer is straining. Informal caregivers share a similar problem, although they only care for one individual, they do not possess the expertise of their professional counterparts and these individuals have diminished physical capabilities. Performing their task creates an even greater strain on their bodies and may lead to injuries.

2.2.4 **Concerns with caregivers health.**

Those who receive care are dependent on the assistance that is provided to them by caregivers. If the health of the caregivers ought to deteriorate, the same can be seen happening with the health of those who receive care. Caregivers are dependent on their physical and mental fitness to be able to perform their duties. Even so, several other conditions may influence their health [18], [19].

2.2.4.1 Physical injuries

The most common type of injuries that are sustained by caregivers while performing there tasks are musculoskeletal injuries. This designation may be used to describe injuries that affect muscles, tendons, nerves and bones. The cause of stress on these organs can be due to the caregiver repetitive execution of the same motion or constant application of excessive force, thereby creating musculoskeletal injuries. If left untreated may result in work-related musculoskeletal disorders (WMSDs) effectively preventing the caregiver to continue in this line-of-work [20], [21].

2.2.4.2 Mental health

In the home setting, the emotional, physical, financial demands of caring for a bedridden individual are responsibilities that fall upon family. High levels of stress start to emerge and both cares and patients over time and mental health stars to deteriorate. Caregivers working in the health care system have a similar psychological issue derived from stress. This condition is known as "Burnout syndrome" and is characterized by high levels of exhaustion, sense of incompetence, frustration low motivation and drive resulting in low performance and efficiency in the place of work [22].

2.2.4.3 Hygiene

Risk of infection by fungi, bacteria and viruses is a serious concern wen treating elderly individuals. In order to minimize the risk of infection the use of protect clothing is recommended. Also cleansing utensils and the local where care is provided significantly decreases health risks and prevent the spread of diseases.

2.2.4.4 Workplace conditions

The living conditions, social involvement and access to proper equipment sources of motivation or lack of it. Having the proper conditions can greatly improve the quality of work that is provided alongside providing safer care experience. Proper conditions help minimize the risk associated with physical injuries, mental health and hygiene.

2.3 Mobility and repositioning assistance devices

Mobility refers to the ability to move from point A to point B by means of some sort of motor function. Alas, bedridden individuals are so labelled do to the fact that their mobility is impaired. Nevertheless, equipment to aid them in recovering some of that mobility exists. Any instrument that assist, increase or improves the mobility capabilities of people with disability are considered a mobility assistive device. Additionally, since they help with ADL's they can be entitled daily living aids. The purpose of these tools is to provide some independence of movement thus improving physical and psychological health. However, many of these applications are only design to help with a certain situations and are designed to provide assistance to the caregiver rather them promoting the BEP independence.

Equipment such as canes, crutches and walkers greatly help impaired individuals to increase stability and balance and provide a functional support with walking. However, provide little or no assistance wen the same individual wants to reposition himself in a chair or a bed. For this purpose be bed Rail or support bars are more appropriate since they provide a fix point of support on which the individual may apply force to move and reposition himself. If the case of individuals that what to exit from a sited positing devices like a lift chair or lift cushion are more appropriate but these devices must be placed beforehand and do not aid or provide support to the impaired person once he is in a vertical position. Transfer or pivot disks, transfer sling and gait belt are other low-tech solutions that help move and reposition BEP's. However, these devices are not for be used by the bedridden they are devices to be used by a caregiver to assist in the mobility of the bedridden. Wheelchairs also provide a means of assistance with transportation while its user is in a seated position. What is interesting to denote is the wide range in variations of this device. Wheelchairs can simple mechanical devices, receiving their motion either from the individual using it (if he possess the physical means to do so) or by the push and control of a caregiver. However, it can also be self-powered requiring only guidance from its user without them having to provide any sort of force to do so. Movement and control is achieved by means of a set of electronic devices such as controllers, batteries and motors controlled by a user. What is interesting to denote is that this modernization of these devices is spreading, being reformulated to either require less effort or provide new abilities. Walkers for example are gaining new abilities like fall detection or acquiring the ability to easily help its user climb stairs [23]. The healthcare market is also investing in the modernization of older equipment. Figure 9 shows a new take on beds for mobility impaired patients. In the case of this device the novelty is the ability of the bed to rotate on its center so de feet of the patient are facing the side of the bed and assume the form of a chair. This helps the user to effortlessly get in and out of the bed.

Figure 9 - Rotoflex Single Bed Turning System (adapted from [24]).

Even with this modernization of older types of equipment or the introduction of new ones, the expertise of a trained caregiver, capable of operating these devices, is always an increased factor of safety and confidence. Patient lift, seen in Figure 10, and ceiling lift are a good example of modern equipment that in the hands of a skillful operator can greatly improve the BEP daily life.

Figure 10 - Patient transfer with patient lift (adapted from [17]).

Patient lift and ceiling lift are similar in the functions that they provide but differ in the manner in which they do so. Ceiling lift follow a pre laid track wile a patient lift possess an independent structure equipped with wheels. These devices recommend that two caregivers be present during its operation. This is due to the devices not possessing any sort of safety net underneath so any blunder can cause severe damages to the person being lifted. Hospital beds have also undergone changes, newer models come with more functions be it for comfort or practicality. However, most of these functions are conceived with the idea that a trained caregiver will handle most of the operations. Therefore, these developments are more inclined to facility the caregivers work than to provide autonomy to the BEP. This does not mean that wen promoting solutions to assist mobility a solution that is more oriented to be used by a caregiver is less desirable. On the contrary the easier it is for the caregiver to assist the BEP the better it is on both parties. The bathing of BEP is an action that requires understanding and collaborations from both the caregiver and the person receiving care. Bathing systems currently available on the market are very versatile since they cover several types of mobility impairment. Some possess walk-in (Figure 13) or side-entry feature (Figure 11) that can accommodate for the type of feebleness of the elderly individual. Others possess own transfer chair (Figure 12) to assist the impaired individuals.

Figure 11 - Rane RR-7 Nuvia (adapted from [25])

Figure 12 - Apollo Advantage 6300 (adapted from [26]).

Figure 13 - ANL5336BF (adapted from [27]).

Other options include an inflatable bed bathtub that can be inflated by means of a vacuum on the elderly bed. The respective handheld showerhead can connect to a sink tap and the system drain hose to the sink drain. This device can simulate both a shower or a bathtub by draining or not the water in the bath. Showers create a soothing effect on the skin and it is desired that the bedridden individuals participate in full in there hygiene routine since this promotes independence and self-esteem. When selecting devices to assist mobility one must be ever mindful of the needs and requirements of the BEP and only then can factors such as versatility, adaptability, privacy, safety and cost-effectiveness are to be taken into account. Be it complex hospital beds or bath systems, the major issue of solutions to assist mobility moving the individual in the more humane way possible without compromising is privacy and not causing him arm. These are the challenges that the developers of such applications must face. The bath routine, for example, is one of the situation that most affects these three points. The action of bathing is in itself something that one does in private however, these individuals require assistance and/or supervision from a caregiver. Also designing something to move and reposition human beings, without them feeling like a package or product, in a human fashion is also difficult. Adding to this the requirement of making these actions happen with the occurrence of injuries is much more so. The following devices come from both the academic environment and private sector and are some of the mobility assistive devices, not yet implemented in the present market, found over the course of this work. Although these solutions are shown here in a sequential form, they were found in a different chronological order during the course of this work. The aim here is to provide a glimpse of what is still being developed or as not yet reached general public knowledge. Italian engineers have developed the Sit-to-Stand (STS) which is a device being developed in the academic setting. Its main purpose is to aid disable people with the seated to standing activity. It greatly resembles a scissor lift and works by being positioned, without contact, under the user armpit and then proceeds to lift the user. Caregiver's perform this activity in a similar manner but their approach requires them to apply force. With this solution, that is no longer the case [28].

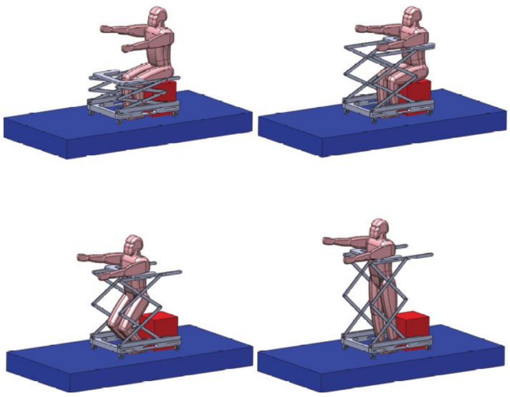


Figure 14 - A sequence for the simulation of the STS [28]

Another device in development in the academic setting is this multifunctional bed. It possess both posture changing and body transferring functionality. This device is interesting since it very similar to regular hospital beds but also possess a conveyer belt system as its bed frame. This enables this device to transfer patients between itself and other devices similar to it. With the configurable bed positions, this device can even adopt a configuration similar to that of a wheelchair for example [29].

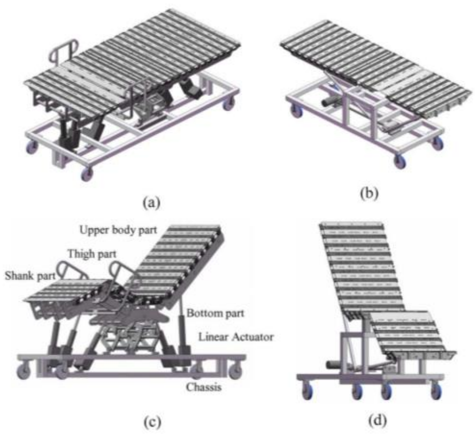


Figure 15 - Multifunctional Test Bed for Bedridden [29].

The C-Pam (or Careful patient mover) is a product that consists of two conveyer belts on top of each other. The bottom conveyer acts as a track that moves the device laterally. The top conveyer serves to add material underneath the patients while the device advances. After the patient being totally placed on top of the device the top conveyer stops and the device retrieves the patients by means of only the bottom conveyer. All the control systems, motors sensors are located in a casing on the side of the device. This means that then approach to transference can only be performed from one side [30].

Figure 16 - Careful patient mover (C-Pam) (adapted from:[30])

The power nurse, shown in Figure 17, is a device developed by Astir Technologies that utilizes the same top/bottom conveyer system as the C-Pam. The difference in this device is that it possess its control and motor components centered inside the device. With this configuration, the power nurse can operate from both sides of the bed and even be a transfer device between to existing beds. This device is a standalone application that rides over a standard hospital stretcher and so cannot move by itself the patient from one location onto another. The concept can be further analyzed in the devices patent with the number US8601619 B2 [31].

Figure 17 - PowerNurse™

Conferring a wheelchair form to these devices is very challenging. The Patent EP 2428197 A1 describes an approach to do so. It is described as a wheelchair that provides a lateral transfer and its conveyer modules are driven by a tensioned wire element that pass through all modules and are powered by a single motor [32].

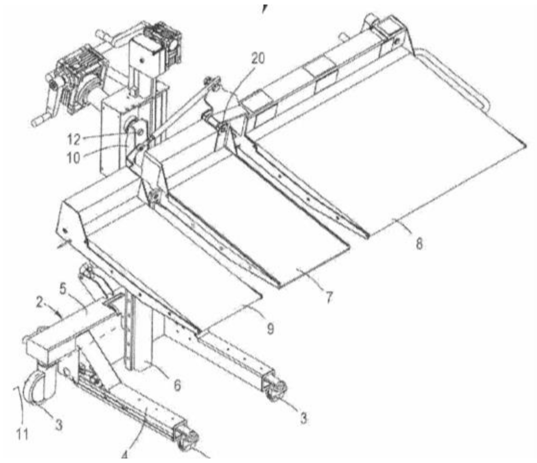


Figure 18 - Apparatus including a device for transferring a patient from a bed to the chair [32]

These conveyer type systems are not limited to lateral movement. Patent US 2012/0299353 A1 seen in Figure 19 describes a wheelchair/ bed system that retrieves and deposits de patient directly from the wheelchair onto the bed.

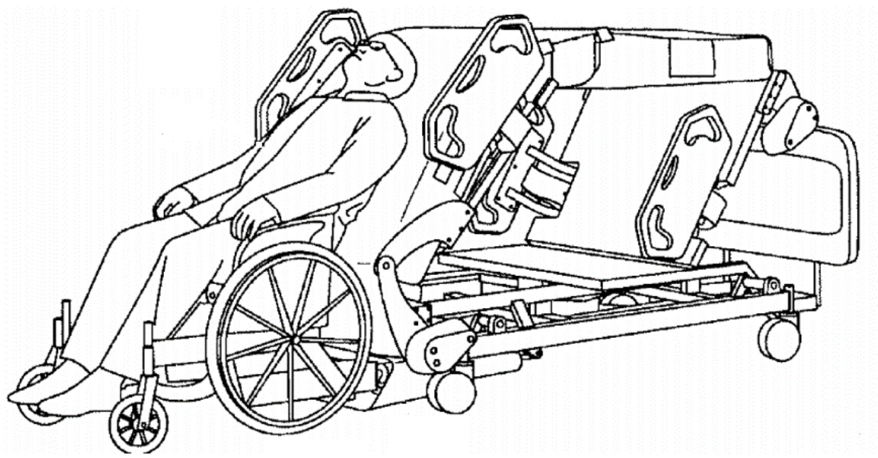


Figure 19 - Frontal approach for a conveyer type system

2.4 New assistive technologies

When new technologies emerge to better our daily lives they do so aspiring to solve a need. The aim of the systems discussed below are to enable elderly people to independently live longer in their own homes, enhancing their living quality and to reducing the cost and burden society and public health systems [33]. Some devices are already proving there worth, for example the use of mechanical patient lifts as decreased musculoskeletal symptoms and injuries among health care workers [34]. Such solutions are beneficial for all since the patient enjoys an aid to mobility, the caregiver strain and effort is reduced and the entity that manages the care (be it private or public) as healthier and more productive workers and satisfied "clients". The technological advances of recent years have provided us with new tools to improve on what already has already been done as well as created new solutions to better care for all of us. The term *Assistive Technology* can refer to several concepts, products and services that independently or combined provide assistance with a task that without those means would require additional effort or would not be possible [35], [36]. Ambient assisted living (AAL) is a gerontechnology that emerges from Assistive Technology with the goal of caring for an individual with some sort of limitation or impairment in his own environment. AAL aims to enhance quality of life through the development of an ecosystem of products and services. It does so by providing an interaction platform that connects the impaired person to several devices and services that combined provide care. Being always mindful that said interaction must take in account the limitations of the individuals for which the care is intended. Several AAL programs have sprouted in recent years and has given birth to a whole movement of research opportunities, large-scale EU projects, (public-private partnerships) with the intent of bringing to market tangible solutions as soon as possible. Some examples of these are the "AALIANCE - The European Ambient Assisted Living Innovation Alliance", the "Active and Assisted Living programme" and the "aal4all" initiatives. To better understand the scope of AAL it is best to provide a description of an example scenario. One of these examples may comprise a product and/or service that can monitor biomedical data of the individual and alert you to any spot situation or even notify the authorities in case of emergencies. AAL not only makes the monitoring of individual is possible but also can also monitor their surroundings alerting him or caregivers of any event out of the ordinary. Through the use of data acquisition devices, the intervenient can be made aware of events such as devices left turned on, fires or a case of home invasion. The system can also responded automatically to these events such as turning of the device, applying fire countermeasures in the case of a fire or calling the police in the case of home invasion. In addition, when applying healthcare and health prevention technology to AAL, solution such telepresence and telemedicine can improve the quality of healthcare that we provide to the elderly [37].

The AAL solution would also be responsible for environmental control depending on the needs of its user but not necessarily need his input in order to achieve the optimal temperature and humidity. This is what is called Environmental Control Systems (ECS), which can also be found in Domotics solutions. Many similarities exist between Domotics and AAL since both act on the user's environment. Where Domotics is the use of automation technologies and computer science focusing on the home setting by customizing aspects of daily life based on user-defined criteria's. Where AAL differs is that it focusses on the human aspect concentrating efforts on the person care and needs. Hit extends on what Domotics provides and complements with a new level of comprehensive technologies directly intended for healthcare [38], [39]. A survey of other presently available AAL solutions can be consulted in Annex F – Emerging technologies related to AAL.

2.5 Design methodology and related Standards

AAL still does not possess a precise definition due to lack of consensus among the scientific community on which concepts, products and services ought to compose AAL. This lack of a precise definition hinders the draft of an official AAL standardization. For AAL to become accepted uniformity among devices must be established in order to guaranty compatibility. Standardization brings with it an insurance to its user that it was manufactured following some criteria and that the device is compatible with any other that follows the same standard. Standardization is not only beneficial for the end consumer but also for the manufacturer among other reasons due to cost reduction and market fairness due to regulation [40], [41].

Several workgroups are developing what they consider to be the framework for AAL to guaranty integration between systems. The European AAL JP and the Standardization Management Board Study Group 5 (SMB/SG 5) are two examples of groups that are forwarding advances in AAL through the use of Information and Communication Technologies (ICT) and from which may derive one or several AAL standard. Although there are, several regional and national standards future AAL norms and regulations will surely abide by an iteration of ISO (International Organization for Standardization), IEC (International Electro technical Commission) and/or ITU-T (International Telecommunication Union) international standards [42]. In the case of medical devices, that comprises the most of AAL devices, the main ISO standards, which is the most consensus-based standardization, to follow are ISO 13485 and ISO 14971 [43], [44]. The ISO 13485 describes the quality management system for the design and manufacture of medical devices. ISO 14971 dictates the requirements for risk management to determine the safety of a medical device by the manufacturer until the product end of life. Medical devices must possess a CE (European Conformity) before being placed in the EU market. The procedure to obtain a CE marking is in general a three step process, determining the class of the device, choosing the CE procedure to apply and declaring CE conformity of the device. The procedures for making a medical device are shown in Figure 20 [45].

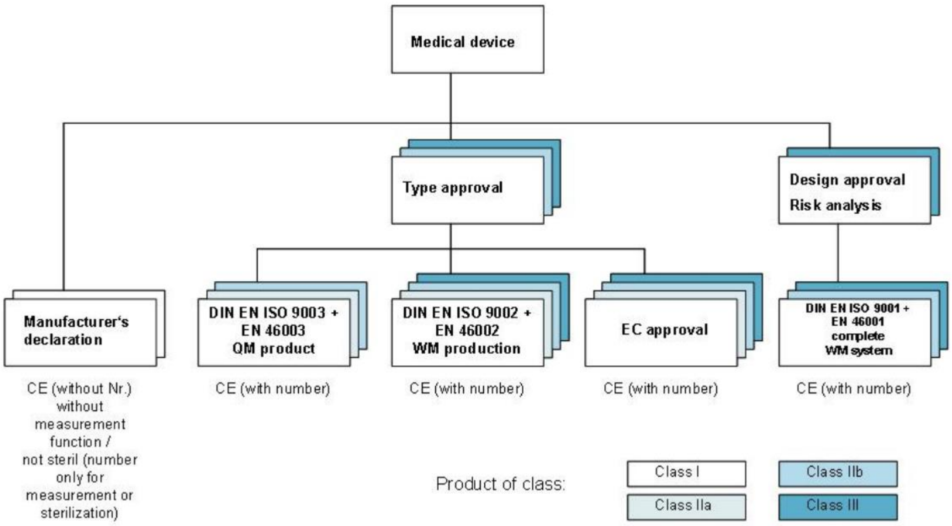


Figure 20 - Procedures for CE marking of medical devices according to the classification CE [45]

As previously stated in the *Objectives*, the aim of this work is to develop a mechatronic solution to aid in moving and repositioning BEP's. For this purpose, this work will follow the VDI 2206 a guideline created by the German Association of Engineers (VDI) in 2002. The lack of an ISO documents for mechatronics design process makes this guideline a perfect standard for the development of this project. Although no direct ISO standard exists for the purpose of mechatronics design these norms are pertinent:

- ISO/IEC 15288 (2002) Systems engineering - System life cycle processes;
- ISO 11442-5 (1999) Technical product documentation Handling of computer-based technical information Part 5: Documentation in the conceptual design stage of the development phase;

Still, these are lacking in their approach to a multidisciplinary area of such high complexity as mechatronic systems design. The VDI 2206 is entitled "Design methodology for mechatronic systems" aims to aid in the product design process of innovative solutions that combines mechanical, electrical and computational engineering which are the bases of mechatronics. Before VDI 2206 two main, other standards were used VDI 2221 and VDI/VDE 2422 but in the scope of solutions that combined such diverse systems they no longer were current. VDI 2221 entitled Systematic approach to the development and design of technical systems and products" concentrated only on the development methodology of mechanical components/solutions and VDI VDI/VDE 2422 entitled "Systematical development of devices controlled by microelectronics" issued in 1993 is outdated with bases on old software paradigms that no longer are up-to-date. VDI 2206 aims be a complement to these guidelines by incorporating the most recent design approaches. The mechatronic design methodology does not follow the sequential approach to the design process. Instead, it uses the concurrent approach so all actors of the design process may contribute simultaneously. The collaboration results in a product that efficiently embodies the established specifications. VDI 2206 uses a tool from software engineering called the V shape model, shown in Figure 21, to its concurrent approach to problem solving [46].

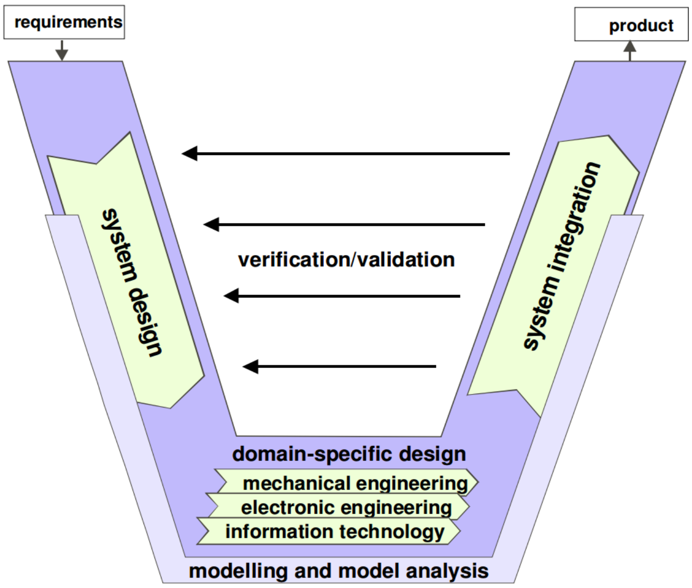


Figure 21 - V-shaped model on the macro-level [46].

The V-shaped model begins by defining the intended purpose and trough this definition obtain in form of requirements the proposed intents of the object. These set of requirements will be the base of comparison with the developed solution that when met signify the development process conclusion. During the system design those requirements are taken in consideration to create abstraction to describe the physical and logical functionalities and sub-functionalities of the intended object. In the system modeling and model analyses phase these functionalities and sub-functionalities are better represented with the aid of domain specific models. Physical model are obtained by graphically describing the system properties in a domain specific form. Mathematical model are obtained by formulas that describe the behavior of the system through mathematical descriptions. Numerical model are obtained by using the mathematical model for representing data through computer tools or simulation. The result of each specific domain are combined to form a complete system and proceeds to verification and validation. Verification examines if the developed system meats the set requirements and if it followed what was set by domain specific tasks. The validation phase consists of testing the developed system to determine whether the product is meets the intended purpose. If validation does not pass regenerates another macro-cycle as shown in Figure 22. When the macro-cycle ends, the result is a product that meets the established requirements [47].

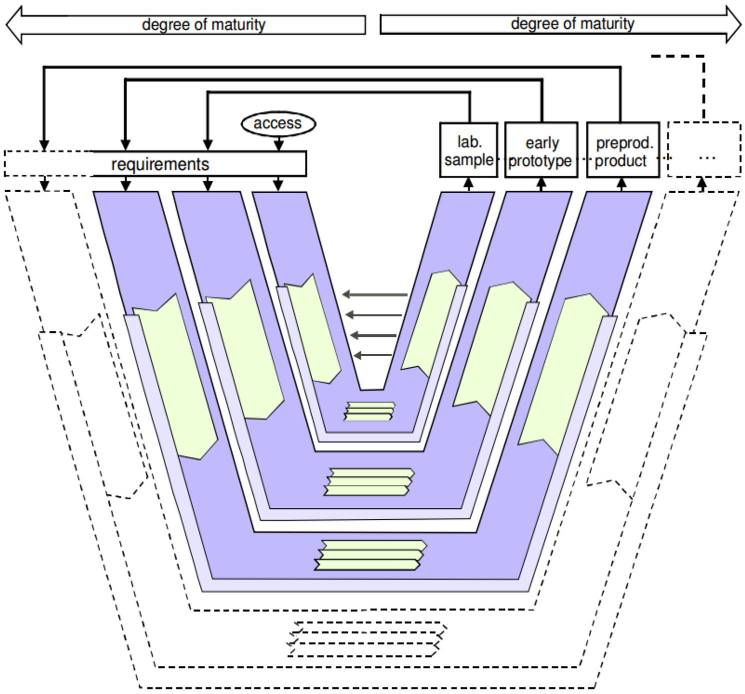


Figure 22 - Proceeding with several passes (macro-cycles) and increasing product maturity [46].

These are the main standards wen considering this type of applications however, throughout the development of this work, references to other standards will be made which will only become relevant in the context in which they are referenced.

What to retain from chapter 2

Chapter 2 provided a more comprehensive definition of both bedridden elderly persons (BEP) and caregivers. These were provided with added information regarding their daily activities and the struggles that they face. The BEP's stigma of reduce mobility affects both their physical and psychological health. This lack of autonomy also impairs their relations and collaboration with the persons in their surroundings. Persons like their caregivers that are also affected by physical and psychological strains when providing care. The physical burden of moving an elderly alone is the major factor of distress. The presented techniques and equipment's that are currently available do not cope with what is demanded of a proper solution. An indication of what is currently available to the public, what is being developed and what can we expect from assistive technologies as also made in order to provide a better understanding of the current state of the art.

Chapter 3

Influence of human body dynamics in the development of a mechatronic solution

This chapter shows human biomechanics information relevant to the context of the solution that is being developed. A brief description of the body positions that a bedridden person may adopt is shown as well as the location of pressure points. The distribution of the human body weight and height is analyzed. This data and consequent analysis will provide the operational specifications for the development of the mechatronic solution.

This chapter intends to demonstrate the train of thought regarding the maximum load and device dimension specifications for the final solution presented in Chapter 5. Until this point, the mass of the individual was considered being applied to a specific point and the dimension values were obtained considering dimensions of hospitals beds currently available. These values will now be obtained from data gathered from different sources and when needed will be subjected to further analysis and/or calculations.

3.1 Dimension analysis

IEC/EN 60601-2-52 is the new standard approved by IEC and ISO members that convers homecare, nursing homes and hospital beds.is. This standard comes to replace the IEC 60601-2-38 (first international standard published for electrically operated hospital beds) and the EN 1970 (European standard for adjustable beds for disable people). Regarding the length of the bed, what is stated in these standards is that there is no required fix dimension for the distance between the head end panel and the foot end panel. This means that manufactures of beds for the healthcare industry may produce different length beds and still be in conformity with the standards. It is ordinary to see manufactures produce beds with a distances of up to 2300 mm between head and foot panels but the most common length is 2000 mm. From the data in Annex A (that shows the percentile distribution of height in the American population from 2007-2008), it can be observed that beds with 1981 mm (6.5 feet) will cover over 99% of the population. Combining this information, it can be concluded that a device with a length of 1980 mm will cover the larger part of the population. Regarding the width, anthropometric estimates for Swedish and English adults (see Annex A) states that the shoulder breath for 95% of the male populations is under 510 mm [48], [49], [50]. These data are important because it is necessary to provide a fairly flat area on which the shoulders can rest without causing discomfort. If this surface is curved in, compression of the thorax occurs if this area is arched the individual may fall off the device. After this initial width, the rest of the device must take into account the placement of arms. Since the device being developed is for the home setting the dimensions of the doors must be taken into account. In accordance to DIN 18100 (Doors; wall openings for doors with dimensions in accordance with DIN 4172) and ISO/TC 162 standardized wall openings for the home setting usually possess a width of 625 mm, 750 mm, 875 mm and 1000 mm for a single door setup. These values are for the doorframes and are not the usable clear opening width. Italian accessibility regulations state that internal doors must have at least 800 mm of usable clear width while Scottish Building Standards state that this value must be at least 775 mm where a door is approached head-on [51]. The Portuguese law of accessibility indicates that an interior door must possess a clear width no less than 770mm [52]. To follow the appointed regulations and in order to clear the door the device must possess a width inferior to 770 mm while considering clearance.

3.2 Maximum mass load

The mass of the individuals for whom the mechatronic solution is being developed will have a great impact on the device max load specification. Projecting the device for exaggerated loads can limited the design, functionality and affect overall costs of the final solution. So a mass value that convers the largest number of potential users must be defined. The values in Annex C - Cumulative percent distribution of populations by weight and sex (2007 – 2008) will be the reference used to define the maximum load. This table provides data on the percentile distribution of the mass under a value, separated by age and sex, of the US population. Its analysis indicates that if the maximum mass specification is set to 155 kg (approximately 340 lb.) the designed device may accommodate 98,8% of the population [53]. With the maximum mass specification determined, another analysis may be performed revising the weight impact of individual human body segments.

3.3 Position of the BEP

For the development of the proposed solution only BEP's lying down (*decubitus*) will be considered. As shown in Figure 23, they can either be lying on their back (*dorsal decubitus*), lying on one side (lateral decubitus) or lying on their stomach (*ventral decubitus)*. Wen moving bedridden people it is preferred, for stability and safety, to move them in the *dorsal decubitus*.

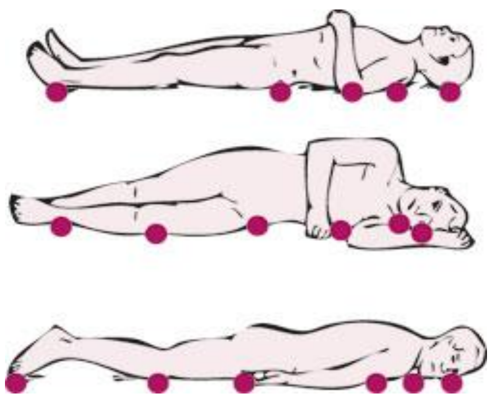


Figure 23 – Decubitus [54]

3.4 Human body segmentation and workload distribution

Some explored solutions have been designed taking into account only a general weight value applied to a single point for the entire device. Thus far, this has served for the purposes of an abstract analysis but for further development, a distribution of the workload must be taken into consideration. However, in order to perform this workload distribution a more detailed analysis regarding individual body segments is required. A pressure mapping of an individual laying down, shown in Figure 24 (unit mmHg), reveals in more detail the areas of the body segments that apply more pressure wen the BEP is in *dorsal decubitus*. The body segment in question are the Head, upper back, the elbows and arms, the area around the sacrum, the calves and the heels [55].

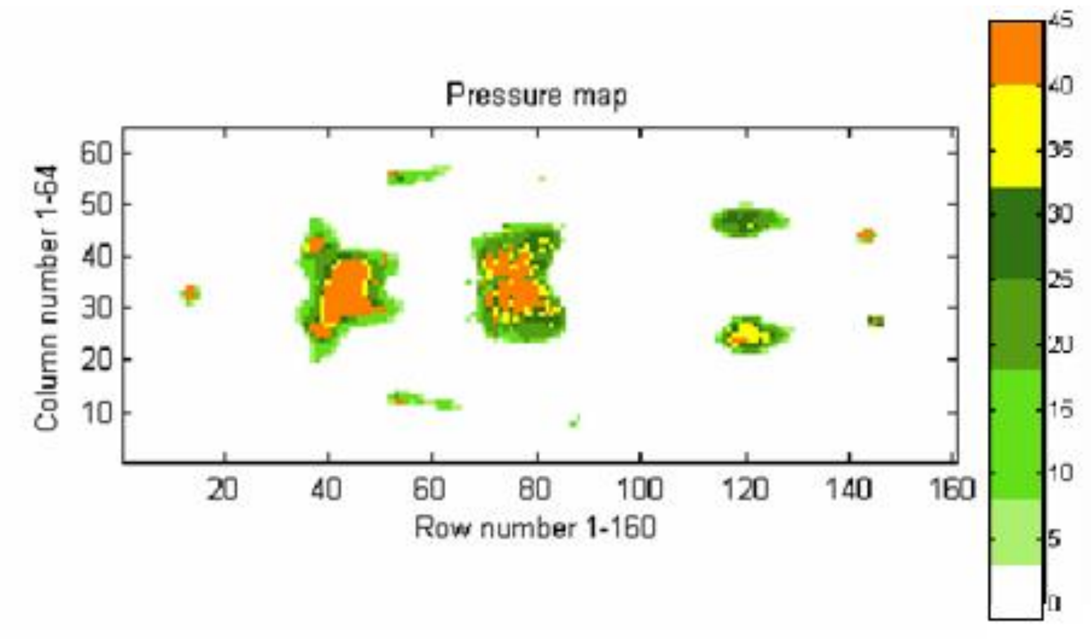
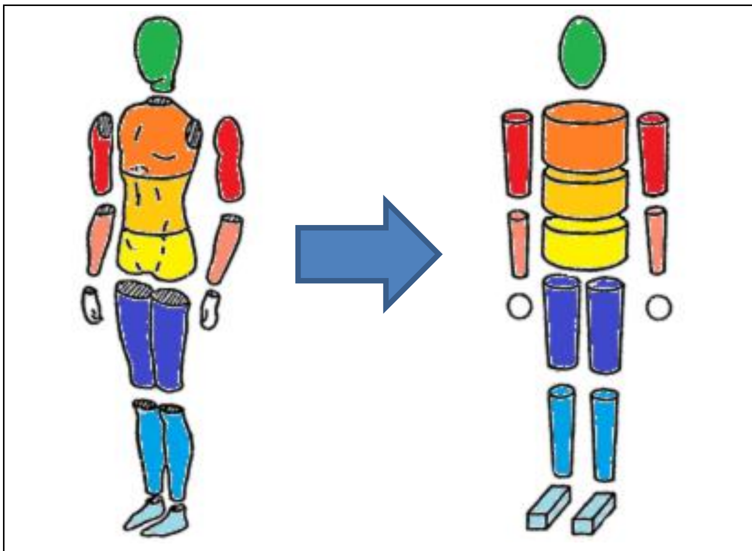


Figure 24 - Pressure mapping on a sensor array of a person laying down with thin mattress (adapted from [55]).

Two major areas of low pressure can be perceived, the first is the area where the abdomen should be located and the second is between the upper thighs and the knees. These two interruptions suggests a possible distribution of the workload into three section, upper section (Head, upper back), middle section (pelvis) and a lower section (calves and the heels). One could also consider two more section, one dividing the Head and upper, and another dividing the calves and the heels. However, the head and heels weight impact do not justify this separation.

Now that it has been determined that the device will be composed of three sections is necessary to analyze the weight applied to each of them. This is necessary in order to better distribute the workload amongst the various sections of the device. For this purpose study's regarding, biomechanics were consulted. A first study considered the following segmentation and percentile value of total weight: Head (7,30%), Upper arm (2,70%), Forearm (1,60%), Hand (0,66%) Trunk (50,80%), Thigh (9,88%), Lower leg (4,65%) and Foot (1,45%) [56].

These percentile values will be applied to the previously defined maximum weight specification. However, this segmentation of the human body considers the trunk region as a single piece. This section of the body is where more than half of the body's total weight is located and thus defeated the purpose of this analysis. Another study proposed the segmentation of the human body as represented in Figure 25.



Head and neck	
Arm	
Forearm	
Hand	
Thorax	
Abdomen	
Pelvis	
Thigh	
Leg	
Foot	

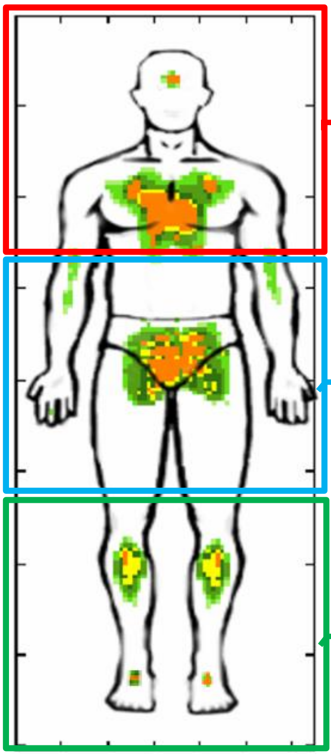
Figure 25 - Segmented body and respective geometric shapes

Applying this segmentation with respective percentile values to the maximum weight specification the data shown in Table 2 is obtained [53].

Table 2 - Human Body mass distribution

Body segment	Relative mass (%)	Individual member mass	Combined mass (Kg.)
Head and neck	8,1%	12,6	12,6
Arm	5,6%	4,3	8,7
Forearm	3,2%	2,5	5,0
Hand	1,2%	0,9	1,9
Thorax	21,6%	33,5	33,5
Abdomen	13,9%	21,5	21,5
Pelvis	14,2%	22,0	22,0
Thigh	20,0%	15,5	31,0
Leg	9,3%	7,2	14,4
Foot	2,9%	2,2	4,5
		Total mass:	155

The distribution shown in Figure 26 provides a better understanding of the mass impact of the body segments that are exerting force onto each section.



The upper section is covers the head and neck, arms and thorax must handle up to 54,715 kg of maximum load.

The middle section is covers the forearms, hands, abdomen, pelvis and thighs and must handle up to 81.375 kg of maximum load.

The Lower section is covers the legs and feet and must handle up to 49,910 kg of maximum load.

Figure 26 - Upper, middle and lower section mass impact.

The middle section is where the most workload will be applied, as such this load value will be the metric for further development of modular sections. With the parameters that refer to the human body properly defined and quantified, we now possess the necessary operational specifications for the development of the mechatronic solution. A summary of the specification can be found in Table 3 - Device specifications.

Table 3 - Device specifications

Device specification		**Justification**	**Value**	**Unit**
Length		99 Percentile population height	1981	mm
Width	Minimum	95 Percentile shoulder width	510	mm
	Maximum	Accessibility standards	770	mm
Maximum Load	Upper section	Mass impact of the body segments that are exerting force onto each section	54,715	kg
	Middle section		81.375	kg
	Lower section		49,910	kg
	Total	99 Percentile population mass	155	kg

What to retain from chapter 3

Chapter 3 provided an insight to the specifications to the device to be developed. These are:

- *The length corresponding to the maximum height of the patient*
- *Minimum and maximum width based on 95-percentile value of population shoulder width and accessibility standards for household doors respectably.*
- *The maximum load specification accommodating for 98,8% of the population.*

To distribute the workload it was found that the device could be divided in three section.

Chapter 4

Studied solutions

The following presents all explored solutions, providing a brief description of on their overall functions and characteristics. The chapter ends with an objective comparison and evaluations that led to the adopted solution. This solution is presented in further detail in Chapter 5.

Many conceptual designs were explored throughout the development of this dissertation. The initial objectives were also broadened since at the very beginning the objective was merely the construction of a mechatronic solution to assist bedridden elderly people. As such the objectives changed from a general goal on to a more specific one, which is to aid the BEP's with the transference between devices, reposition in the bed and transportation in is home setting. These objectives were found to be the predominant issue that required a solution so that the handling BEP's can be performed in a more comfortable and humane fashion.

4.1 Transforming bed design

With this mindset, this first approach intended to solve the issue of having multiple devices to aid the bedridden and assist with their mobility issues. These occupy a great amount of space in the living environment and represent an added cost, for each device, that that hinders the average family to acquire all of them. Taking into account these issues this first concept aims to combine all of them in a compact and less costly device. This resulted in the "transforming bed design". The initial idea was that the bed in which the elderly bedridden person was confined could be transformed into other devices that would offer mobility to its user without the need for him to interchange between devices. The bed mode of this concept is shown in Figure 27 (a). By means of actuators placed in convenient locations this form could interchange between the standing frame mode in Figure 27 (b) and the wheelchair mode in Figure 27 (c).

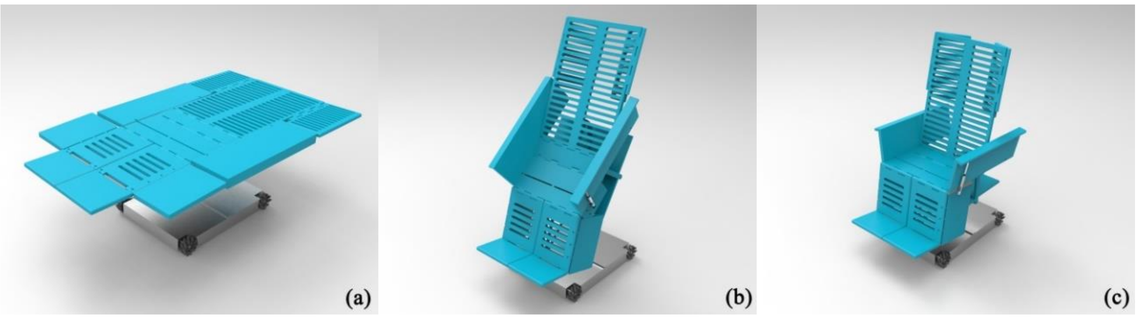


Figure 27 - "Transforming bed" concept ideas: a) Bed; b) Standing Frame; c) Wheel chair.

The wheelchair mode of the "transforming bed" was designed taking into account the DIN 18100 and ISO/TC 162 standards that standardize the field of doors, door sets and windows. This was done by designing the central section of the bed with the dimensions that would permit that the device, either in wheel chair or standing frame mode, to pass through the convectional home door set. Since the bedridden individual is not transferred from the bed onto other devices, the risk of injuries are significantly decreased.

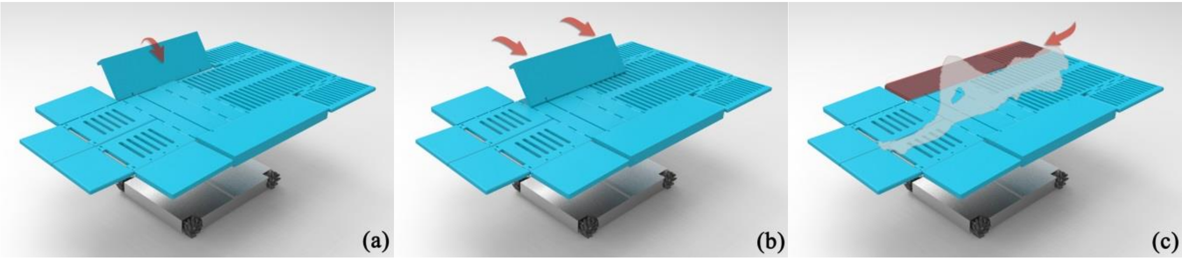


Figure 28 - "Transforming bed" concept: a) Rotating movement; b) Linear movement; c) Bed sheet placing.

Another feature of this concept is the "roll over". When the system is in the bed mode, one of the lateral parts that compose the bed will support the BEP by inserting itself under patient. The motion described by this part is a mix of rotation, Figure 28 (a), rotation movement and linear movement, Figure 28 (b). The translation of the part would enable to tip the patients to his side. This would enable the caregiver to interchange linens one side at the time, Figure 28 (c), reposition the BEP into a more comfortable position and aiding in the hygiene routine (change clothes, give a sponge bath, etc.).

4.2 Drum motor driven conveyer design

This mechatronic system design consists of an extendable structure with a belt conveyor system that is primarily designed to retrieve/deposit the BEP between surfaces. As the conveyor is being inserted underneath the BEP, it functions as a device that adds material under the BEP so that when the structure is being inserted injuries from friction do not occur. To insure that the transference between devices as not limited to devices that had the BEP laying down a tree parte modular belt conveyor system was implement. In Figure 29 the only the middle part, of the three part conveyer system, is shown. The aim with this modular system is so that the overall solution may be configure itself to describe a simple plane surface or a more complex configuration like a chair making for a very versatile application. By reversing, the conveyer belt movement allied with opposite movement by retrieving the structure the application is able to deposit the BEP smoothly onto a position of choice without any risk of injury. Figure 29, shows the simulation that would provide proof of concept for this solution. The device is shown without its belt and protective covers so that the drum motor (1), linear guides (2) and linear actuator (3) may be visible.

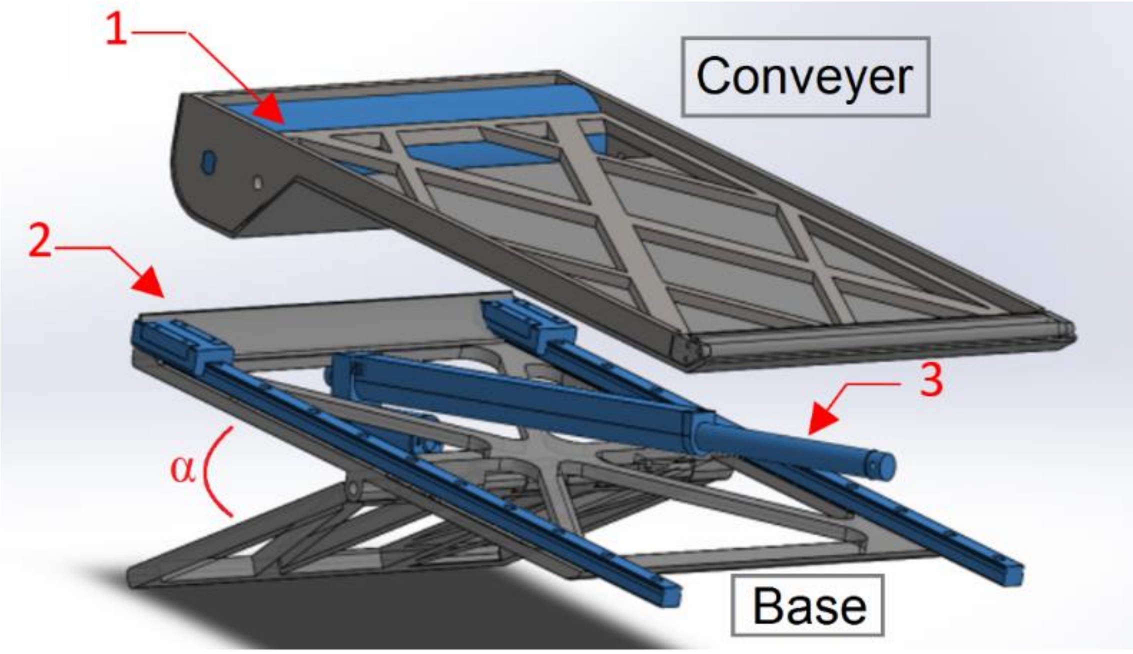


Figure 29 - Conveyer system concept highlights

The device operates by first lifting the base structure an angle α of 8° that coincides with the angle of approach of the conveyer structure. In this position, the base structure is completely horizontal and the conveyer is at an 8° angle. This angle value as found to be the maximum applicable value for the approach angle to retrieve the BEP without causing discomfort although being evident from the start that this value should be reduced as much as possible. This device is placed side by side with the BEP's bed and the knife-edge, located opposite to the drum motor (1) which acts as the drive pulley, is placed on top of the bed. This is so that the knife-edge acts as a wedge for the conveyer structure while it advances. While advancing at the determined angle the conveyer structure describes a linear movement at the same speed that the drum motor (1) rotates the conveyer belt. Thus, no friction occurs while the conveyer belt structure is inserted underneath the BEP. As soon as the individual is completely on the conveyer belt the drum motor (1) stops and the linear actuator (3) recedes the conveyer belt structure. Then the base structure is lowered and in this position, the base structure is at an 8° angle while the conveyer is completely horizontal, from the BEP's point of view, he is completely levelled. To deposited the BEP onto another surface it is just a matter of placing the device next to it and execute the process is the same manner but in reverse order. Related equation that govern this sort of setup can consulted in Annex H – Drum motor driven conveyor design related calculations.

4.3 Ball screw actuated conveyor design

Although similar to the drum motor conveyer concept, this approach aims to improve by using simpler mechanisms and reduce the operational steps to perform its tasks. Additional steps only increased the complexity and probability of occurring problems. In this approach the conveyer drive pulley as discarded to suppress the need for the conveyer to advance inclined. In addition, it was concluded that the device should not have any drive components placed above the plane were the BEP is placed. The inspiration, for the mechanism that would solve these issues, came from an existing device used in the food sector called "Canvas board" as seen in Figure 30. Although designed to deposit bread inside ovens the mechanical principal can be rethought for an application to deposit and retrieve the BEP's.

Figure 30 - Canvas board

The mechanical principal is quite simple the conveyer belt, in this case the canvas, is restrained to a perpendicular bar, in relations to its guides, this bar slides up and own a rail and thus limits its movement to a linear motion. Wen force is applied to the perpendicular bar the whole canvas revolves around the structures. In the proposed ball screw conveyer concept, the idea is to attach the canvas to a ball nut connected to ball screw aided by to linear guides instead of a transversal bar. This concept would solve the issues found in the drum motor conveyer concept by reducing complexity and removing the need for any component to be placed above the BEP plane since all the components can be fitted underneath the conveyer structure. Figure 31 shows the arrangement of the discussed components in order to provide the intended motions. A ball screw as chosen over the lead screw because these devices operate by sliding friction while ball screws use rolling friction and thus reducing the coefficient of friction value while providing higher efficiency.

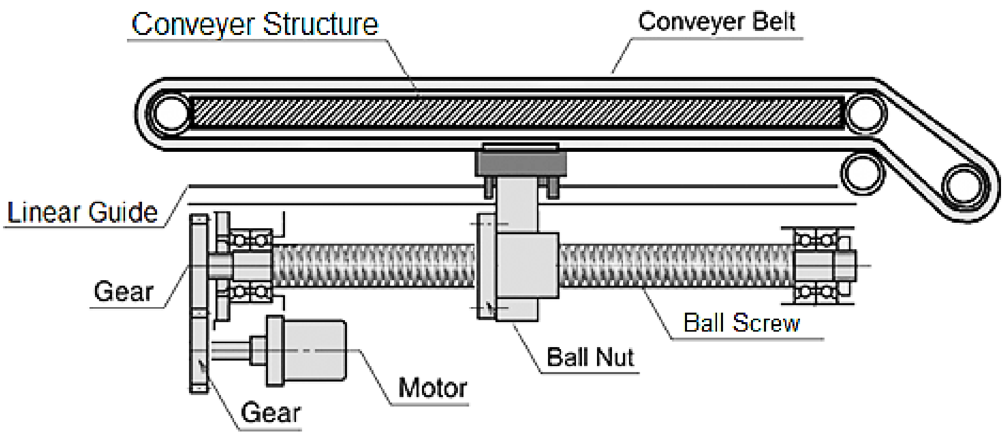


Figure 31 - Ball screw conveyer structure

Ball screw specifications such as efficiency, lead and diameter values can be adjusted to provide a mechanical de-multiplication of force and thus reduce the torque value required from the motor to drive this application. Adjusting these values can greatly reduce the overall component footprint in the application design. The ball screw is mounted to the conveyer structures in a Fixed-Simple configuration in parallel with two linear guides. The ball screw must be used for axial trust only and these linear guides are used to support the load. To prevent backlash, which is the axial free play in the nut, preloading should be applied to the bearing inside the nut. Following the flowchart in Annex D, that that describes the procedure to select a ball screw it is first recommended to define the use conditions.

These condition are load, speed, stoke, accuracy and required life. For the load, the mass of the conveyer structures will be discarded for now. The mass applied as previously been determined in chapter 3.4 and corresponds to the maximum weight applied to single sections witch is approximately 82kg. The friction coefficients between conveyer structure and the conveyer belt is 0.1. The frictional coefficient for NSK guides are between 0.002 and 0.003. The ball screw with the reference number PSS1505N1D0661 was selected preliminary do to its diameter (15 mm), its lead (5mm) and its overall length (661 mm) since these matched what was pretended from this solution. With the ball screw selected, the maximum stroke (559 mm) could be looked up in its respective table. With this data and still following the guidelines of Annex D, we set up to determine the operating torque for this ball screw. The related calculations can be consulted in Annex I – Ball screw actuated conveyor design related calculations.

NSK provides an all-in-one devices called a monocarrier™, which is an integration of several components in one device. This solution is composed of a ball screw, linear guide and support bearing with housing raped around a solid structure. As seen in Figure 32 other components can be mounted to this device such as a sensor unit (1), a sensor rail (2), a cover unit (3) and a motor mounting bracket (4) among others.

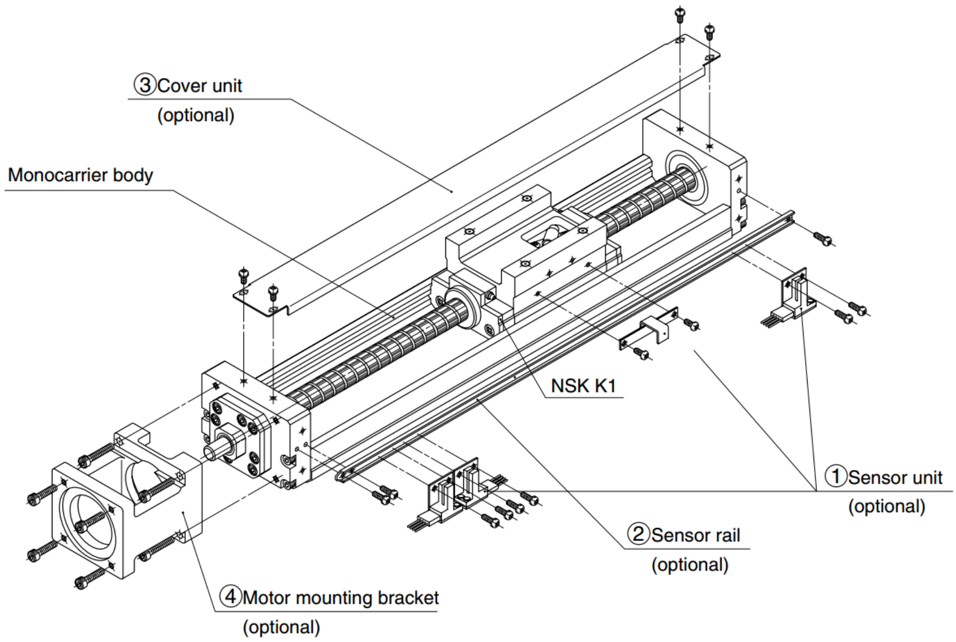


Figure 32 - NSK Monocarrier™

Since it is comprised of, several components required for this concept it seemed a proper "off-the-shelf" device to integrate in the development of this concept. This makes it unnecessary to go through the engineering of each component since this was done by the manufacturer. Looking at the available configurations provided by NSK the MCL06050H10K00 was selected since its overall dimensions, lead and stroke fitted in the desired design. It possess a 12 mm shaft diameter, a 10 mm lead and a 500 mm stroke. Using equation (1) to obtain the operating torque, T_a it is determine that to move the load in normal operation one monocarrier requires a torque applied to its ball screw of 0.71 newton's. Nevertheless, the ball screw conveyer concept is designed to utilise two of these monocarrier for stability and for the workload to be distributed between the two. Following the outlined concept in Figure 31 the 3D CAD rendering of the module shown in Figure 33 without conveyer belt and top part of the conveyer structure. The monocarrier possess a slider that acts as both a ball nut and a guide so to move alongside the width of the module. This device is motorized by an adjacent motor linked to the monocarrier through means of a timing belt. The monocarrier on the upper left of Figure 33 is shown without is cover unit for better visualization of the mechanism. The horizontal bar is connected to both slider on both monocarrier. This bar serves a dual purpose one is to act, as a link to join both ends of the conveyer belt and the other is to secure it to both sliders on each monocarrier so that motion can be applied to it. The conveyor belt wraps around the conveyor top structure and the nose rollers, both not shown in Figure 33.

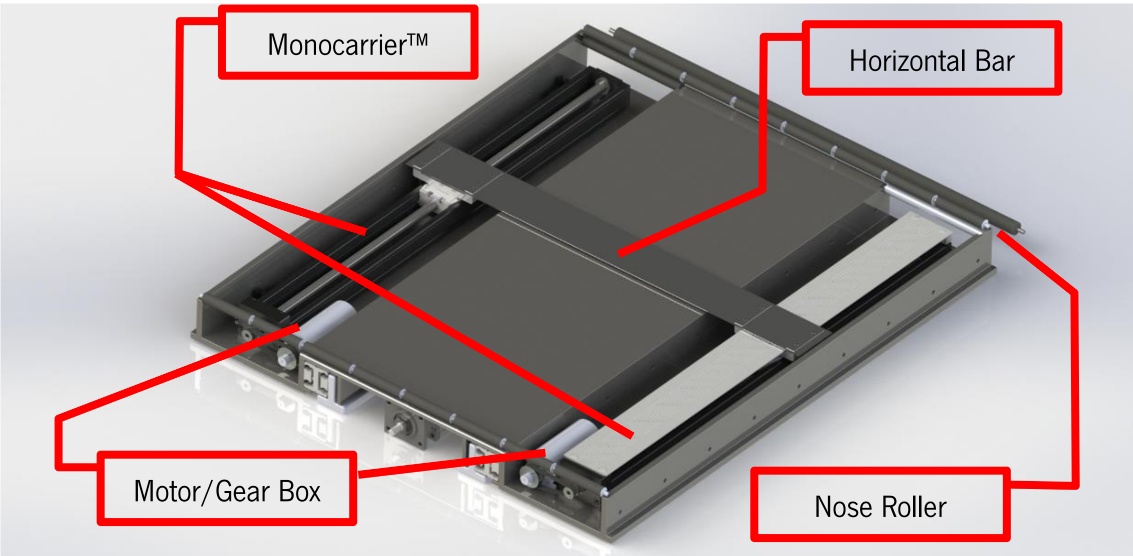


Figure 33 – 3D CAD of the Conveyer Ball Screw design, module inner workings.

Figure 34 shows the conveyor module, now with conveyer belt and top part of the conveyer structure. Both the base monocarrier and the two instance of the support beams are secure to the base structure and there position never changes in relations to it. Motion is transmitted to the base monocarrier through a motor located on the base structure. The two telescopic rails are both fixed to the conveyer structure and base structure. Their purpose is to support the weight of the conveyer structure and the patient (when located on the device) wen the device is extended. The telescopic rails are fixed to the base structure through the aid of two support beams. These possess several screw holes that aligning with the ones located on the telescoping rails in order secure them to one another.

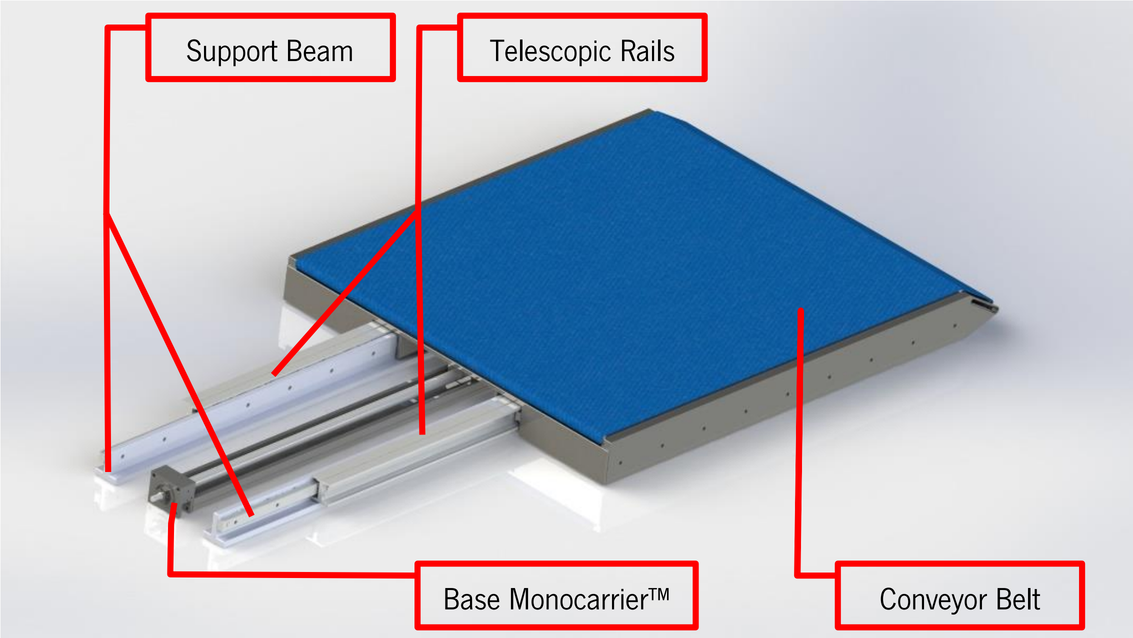


Figure 34 - 3D CAD of the Conveyer Ball Screw design, module extended.

As described earlier, three of these modules are connected in series, to the base structure. The resulting device is shown in Figure 35.

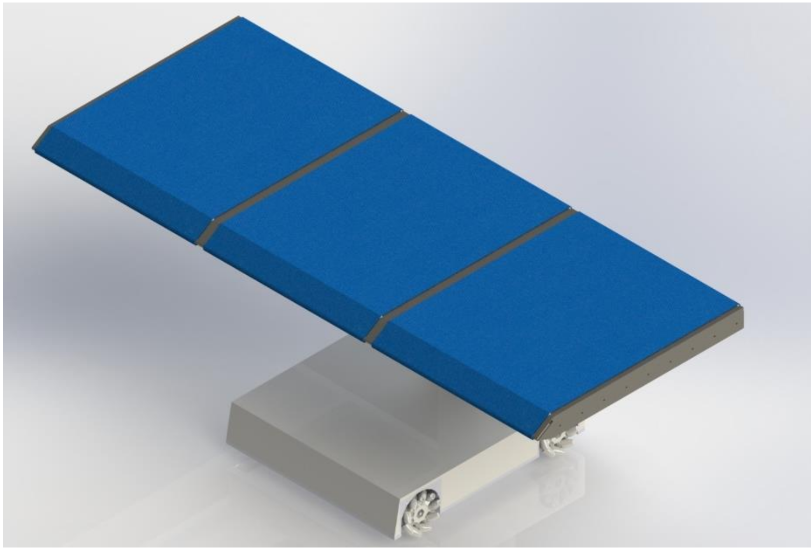


Figure 35 - 3D CAD of the Ball Screw Conveyer design, general view.

These modules are all fixed to each other in such a way that the gap between them is minimized. Nevertheless the small portion of exposed structure must undergo surface finishing in order to minimize the friction with the patient.

4.4 Low-profile center-driven conveyor design

This design was projected with the mindset of a low-profile conveyor module to be inserted under the patient while retaining the ability to extend itself from both sides of its base. To accomplish this the placement of the conveyer drive mechanism is crucial. It was determined that no space is available for the placement of such components on the sides of conveyer module where the nose roller or knife-edge will be place since these are of low height. In addition, no component should be positioned above the plane where the patients is to be placed. Placing any component underneath the conveyer module would compromise the ability of the module to advance while keeping a low profile. Positioning the drive mechanism in any location other than the inside of the conveyer module would increase the system complexity by generating further complications regarding drive force transmission (couplings, belts, gears, transmissions shafts, etc.) and needlessly augmenting costs. The optimal location found for the drive mechanism would be inside the conveyer module at its center in a dual motor configuration, opposite to each other, as shown in Figure 36. The two motors are for both distributing the workload and prevent slippage from the belt.

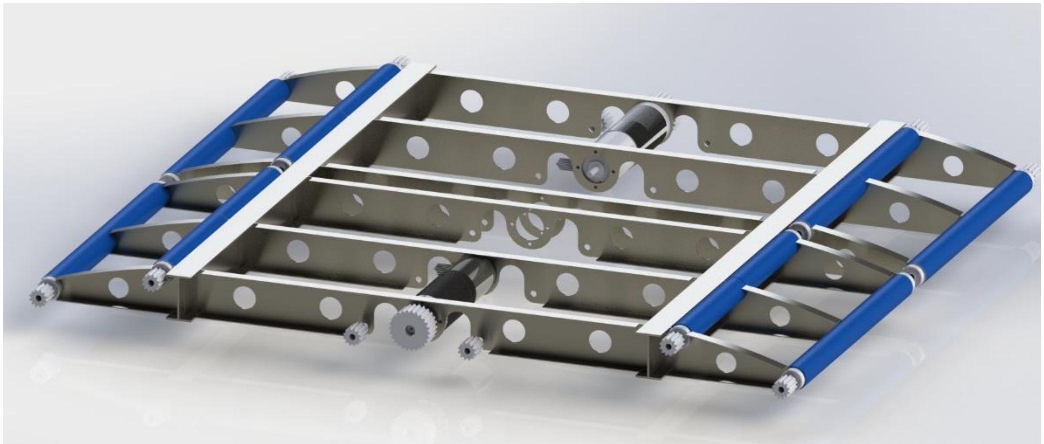


Figure 36 - Conveyor module inner structure.

The conveyor belt is not the power transmission component. In this context it only serves the purpose of adding material under the patient while the device is being inserted. To transmit power between the motors and conveyor belt a timing belt is used. This component is attached to the conveyor belt and is actuated be the motors through timing pulleys. The timing belt wrap around several other smaller timing pulley to describe the path shown in Figure 37 performed by the conveyor belt. An advantage of using timing belts is that one need not to worry about slippage of the belt since the timing belt is physically restrained, when properly dimensioned, to follow its path.

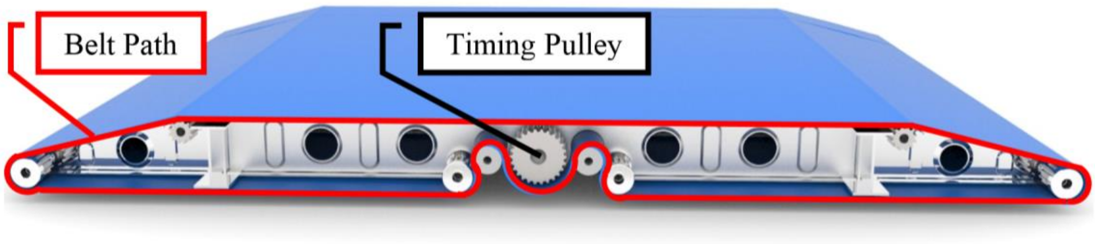


Figure 37 - Timing belt path around the structure.

The two indentation seen in Figure 37 are for two rollers that serve a dual purpose. The first is as a tensioning component for the belts. The second is for providing a larger wrap angle β to the drive pulley. As for the ball screw actuated conveyor design it is also proposes the use of three modules to distribute the workload. To allow for operations on both sides of the device the telescoping rails would also have to be modified. These modifications are expected from the manufactures and documentation on the matter is available with the recommendation that the overall device possess physical limitations to the extension of the rails. Since there is, a need to allocate space for the support of these components a gab must exist in order to connect said modules to the base structure. What is unwanted in this situation is to said gap to causes discomfort or injuries to the patients that are utilizing the device. Since these gaps are only found between modules the solution found was to utilize their respective conveyer belt to drive a smaller one that convers the gap. The pulleys, marked by circular arrows, as rotating in Figure 38, are fixed to a shaft that runs the length of the conveyor module. One of these shafts exits on both sides of the conveyor module. As the centered conveyor belt is driven by the center motors, this belt confers motions to these shafts. They then drive two smaller tensioned belts on each side. The path of these belts describe a smaller profile then the centered conveyor belt in order to create the opening shown in Figure 38 labeled "Attachment opening". The purpose of this opening is to provide an attachment location to the telescopic rail and thus creating a seamless joint between modules such that the break in belt material is negligible.

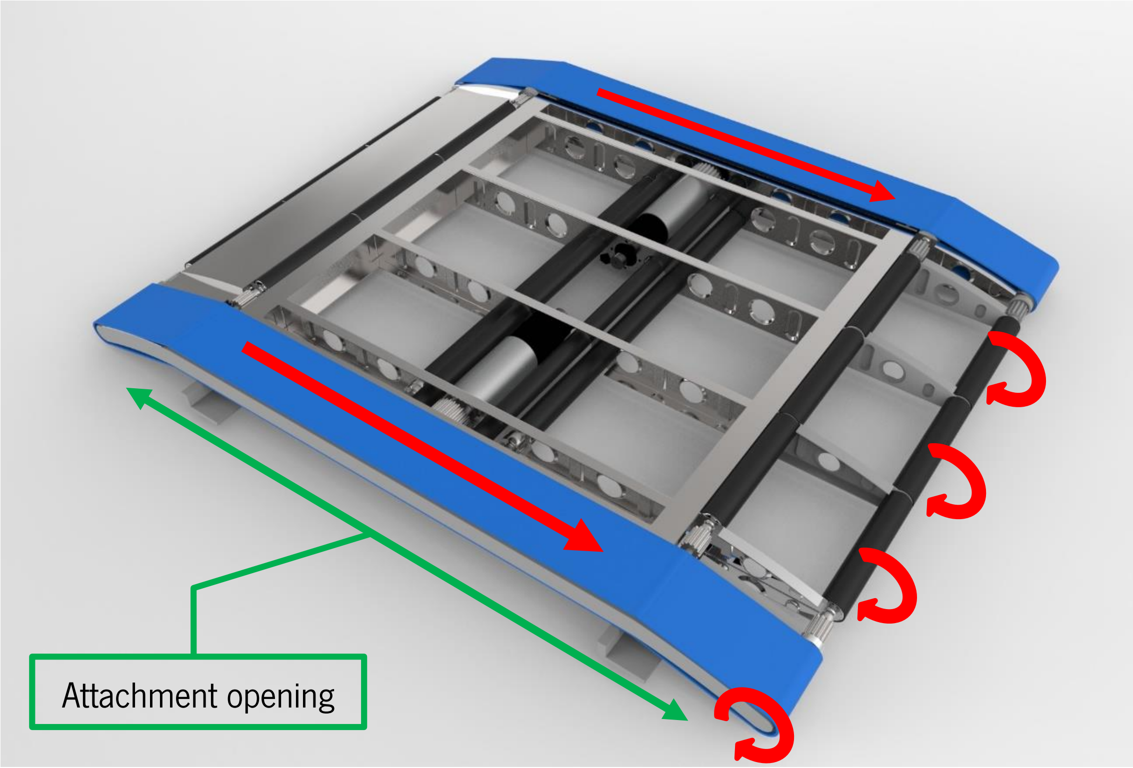


Figure 38 - Inner workings & power transmission

A render of the overall solution is presented in Figure 39. All the mentioned components are assembled in this configuration. The final profile of the conveyor structure is 47 mm, achieving the objective of a low profile solution. In addition, it is worth mentioning that no components are encumbering the space over and under the conveyor modules.

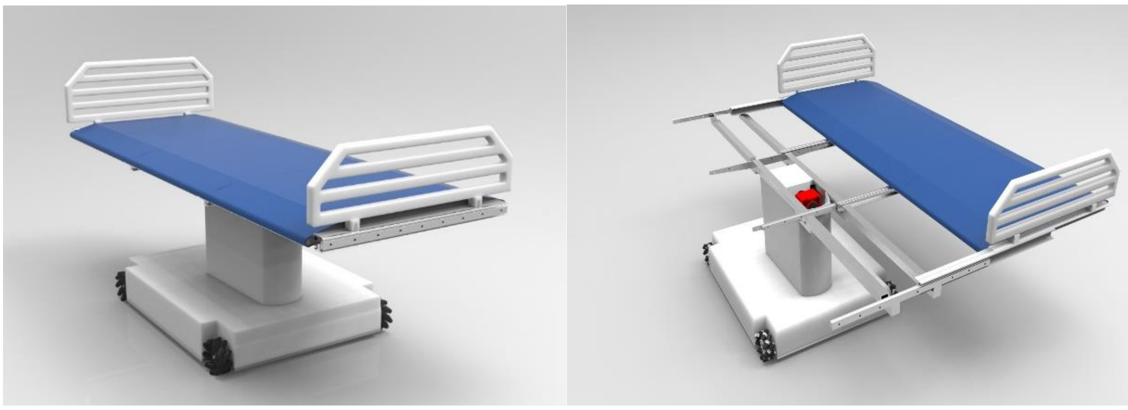


Figure 39 - 3D CAD Rendering of the complete solution.

4.5 Solution comparison and selection

The following is a comparison between designs highlighting some of their features and issues. The transforming bed design solution was not further developed in part due to the overall system complexity and limitations to the distance of travel of the described "roll over" feature. Also this solution had a major design flaw with the dangers regarding the gap between parts and hinges. These could have compressed body parts and create grave injuries. The attempt to solve multiple issues in one devices taught that although possible to construct such a device it might not be desirable. The drum diameter prove to be the biggest issue of the drum motor driven conveyer design. The drive pulley, in this case was a drum motor, diameter influenced the tension leaving and entering the pulley and thus the possible output torque. No currently available commercial drum motors was found that possess the required torque and dimensions values to move the conveyer belt under the specified load. This diameter also influenced the angle on which the conveyer belt structure advanced. For this application the lowest angle on which the device could be placed as at an 8° angle but although feasible it was far from desirable since it leads to discomfort to the BEP. This advance of the structure while inclined also contributed for an increase in the components required and the overall complexity of the design. The ball screw actuated conveyor design also presented several limitations. The first and perhaps most evident is the reduce stroke provided by the ball screw. For the MCL06050H10K00 monocarrier, this value is 500 mm. For this design, this signifies that the conveyer can only rotate 500 mm as such the device may have difficulties retrieving a patient with a broader constitution. The overall width of the module is already reduced to the minimum dimension to conforms with the constrains previously established in chapter 3. Fitting another component to improve upon the stroke value, be it a simple ball screw or another monocarrier, would require a custom part. The use of "off-the-shelf" equipment (such as the monocarrier) constrains the design with their dimensions. These were not optimized to fit in this particular application so clearances and gaps can be found in the overall design. Designing a custom component for this application would require the proper dimensioning of several key components. Other components such as the ball screw, the bearing housing, couplings, motors, gears and/or belts. In this early phase, the engineering of each components is beyond what is to be expected at this stage. The final thickness of the conveyer module was a 54 mm including the conveyer belt. Although a nose roller is used this is still an excessive volume to be inserted under the patient. With the selection of nonstandard components such as smaller guides or ball nuts the overall stoke can be increased and the thickness can be further reduced be optimizing the structure for does components. For this particular concept, which utilizes a ball screw as its drive mechanism, the stroke provided will always be inferior to the width of the module. A rather serious limitation but dos impede its purpose as long as the final stroke is superior to the width of the patient and inferior to the width of the module. In operational terms, this means that this conveyer belt structure must be placed right alongside the patient, preferably with the tip of the nose roller already under his side, and should only revolve wen advancing underneath him. These limitations also imply that the device cannot perform the transference of patients from one local directly onto another. The final flaw found with this concept is the lack of conveyor material that exist over the junction of the conveyer modules. Two such gaps exist in this concept and for the CAD models shown earlier each of these gaps correspond to 32 mm of lack of belt material. Although small areas they may be sufficient to cause injury's do to friction between the conveyer structure and the patients skin. The selection of specific components allied with a redesign of the structure may solve or reduce their impact of some of these issues but as its stands this concept, although practical, is not optimal. The low-profile center-driven conveyor design also possess some concerns. One of which is the sheer number of components required only for the movement of the belt elements. Just the conveyor modules require six motors, six gearboxes, six encoders, three servo motor drivers and also several pulleys, rollers and timing pulleys. These components are only to drive the conveyor and a number of many more are require for other operations such as adjusting the height of the conveyor modules, driving the base structure and advancing and retrieving the conveyor modules from an to the base structure. Adding these devices greatly increases the cost and complexity of operations. The telescopic rails placed under the structure contribute to the height of the profile in certain locations of the conveyor structure. Despite taking into account the flexion of the mattress of the bed in which the patient is located the height of the telescopic rails still hinders operations wen retrieving and placing the BEP.

Despite the appointed issues, each design is not without its merit. In order to determine which of the design is best suited for further development we will resort to the decision matrix in Table 4 based on Pugh's method. By placing, the proposed solutions in columns and making each row correspond to a criteria a value can be attributed for comparison. In this instance the value attributed to the requirements are a range of values from 1 to 10 (1 = does not meet requirements; 5 = Somewhat meets requirements; 10 = Perfectly meets requirements). Adding the scores establishes the optimal choice for the solution to be adopted.

Table 4 – Studied solutions decision matrix

Criteria	**Weight**	**Transforming Bed**	**Drum motor driven conveyor**	**Ball screw actuated conveyor**	**Low-profile center-driven conveyor**
Safety	2	4	2	6	8
Comfort	1,75	7	1	6	7
Robustness	1,5	6	4	7	8
Construction complexity	1,25	3	7	6	7
Handling complexity	1,25	3	4	8	8
Programing complexity	1,25	3	7	6	7
Cost	1	4	5	5	6
Raw Score:	-	31	30	44	51
Weighted Score:	-	32,25	37,5	52,5	61,5
Rank:	-	4	3	2	1

Ranked the highest in the decision matrix, the low-profile center-driven conveyor presents itself as the best design to be developed.

What to retain from chapter 4

This chapter presented the four designs explored for the purpose of this dissertation. All of them with different layout an movement mechanisms. During the study of these solutions, issues were found that hinder the viability or limited some significantly. Issues such as complexity, prone to the occurrence of injuries, discomfort to the patient and technical/mechanical limitations. However, it was necessary to study them, in order to be possible to conclude this. This chapter ended with a comparison of all solutions and in so doing, the most promising design emerged. As such, the foundations are laid for further development of a better and more complete solution.

Chapter 5

Proposed mechatronic transfer solution.

This chapter presents in more detail the proposed design solution and provides a description of the overall concept as well as the inspiration behind it. It does so by briefly re-visiting the limitations found in the other explored designs and describing how it solves them. An explanation on how the solution operates is also presented describing the steps required in order for it to perform its actions. The details of component selection are left for another chapter.

The low-profile center-driven conveyor design will be adopted as the proposed mechatronic transfer solution for this dissertation. Its concept has already been described in the previous chapter however here the design will be more thoroughly described. However, pertinent issues that emerged in other proposed designs relevant to the overall design must first be addressed. Revisiting the design concept that were not selected a few important considerations can be drawn. As shown the ball screw conveyer concept presented itself to be a working solution but not an optimal one. This is mainly due to its short stroke and its inability to operate from both sides of the conveyer structure. Therefore, this solution should be rethought to attempt to resolve both these issues as well as any other that were found during this work. As seen in chapter 3.4 allowing for a more uniform workload distribution among the modules, instead of considering the complete weight applied to one point, yields a reduction in drive force requirement. When compared to conveyer drive seen in the drum motor conveyer concept the weight considered is almost halved. Distributing the workload onto two motor opposite to each other on each module makes for an even greater distribution of the workload and prevents the conveyer belt from sliding out. If the three conveyer modules distribution is to be employed it would be desirable that the gap that connects one module to another be removed or made safe for the patient to be transported over. Revisiting the drum motor conveyer concept it was found that the need for a large diameter drive pulley was mainly due to the requirement of providing a sufficient wrap angle so that a tension could prevent belt slippage. At the time, of the drum motor conveyer concept, a belt drive was considered since the overall design required a conveyer belt to add material underneath the patient. However, a conveyer belt drive is not efficient in this application and presented many challenges wen attempting to fit the required components onto the conveyer belt structure. Attempts to place a drive components off the conveyer structure were found to be unfruitful. Placing these components above the resting plane of the patient is also not recommended. Considering also that the extremities of the conveyer module need to be of a low profile in order not to injure the patients a drive component cannot be placed there. A function desired of the final solutions, and one that the ball screw conveyer concept failed to achieve, is the ability to the operations on both sides of the device. Another issue with the previously explored concepts was that no particular considerations were taken regarding the weight of the base and conveyer structure. It is of interest to keep the weight of the base structure down since this may compromise its use in the home setting. Since the conveyer structure will be actuated to retrieve and deposit de patient special consideration must be taken to reduce its weight. The more this component weighs the more force will be required from its actuator. Taking into account the outlined considerations retrieved from this breakdown of the other design concepts the low-profile center-driven conveyor must consider:

- The placement of the conveyor drive mechanism;
- Prevent the slippage from the belt element;
- Gap between modules made safe or removed;
- Possess a low weight structures;
- Have the ability to operate from both sides of the device;

Chapter 4.4 in which the low-profile center-driven conveyor design was present already addressed and provided a solution to the issues of the placement of the conveyer drive mechanism and slippage prevention of the belt element.

5.1 Gap issue

Since there is a need to allocate space for the support of the conveyer modules an opening must exist so components can be placed in order to connect said modules to the base structure. What is unwanted in this situations is to said gap to causes discomfort or injuries to the patients that are utilizing the device. Since this gaps are only found between conveyer modules the solution found was to utilize their respective conveyer belt to drive a smaller one that convers the parts that connect each module to the base structure. This smaller conveyor belt describes a path that enabled the creations of a small attachment opening were the support elements of the conveyor modules could be connected to the support element that connect to the base structure. This opening is shown in Figure 40. Joining two conveyor modules side by side resulted in an almost seamless connection. The resulting connected elements can be seen in Figure 41connected to their individual telescopic rails.

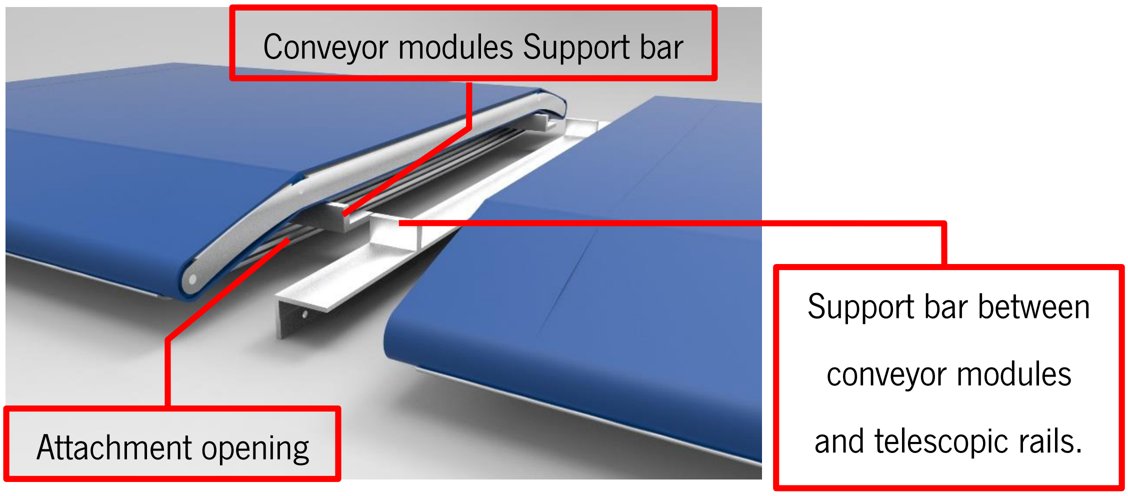


Figure 40 - Conveyor modules opening and support elements.

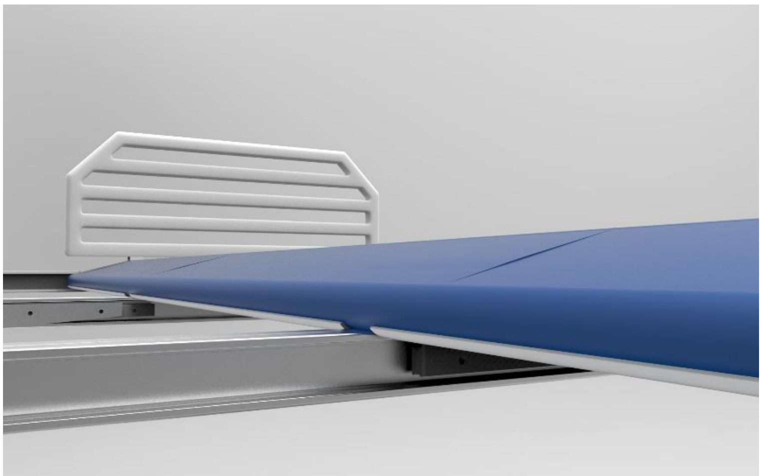


Figure 41 - Conveyor modules supported by the telescopic rails.

5.2 Bed rails safety

Safety rails posses norms, such as the IEC/EN 60601-2-52, that regulate their dimension to ensure safety to their user. This particular norm states that safety rails must be taller than 220 mm counting from the mattress and transversal bars must not be spaced more than 120 mm. also the safety side rails end shorter than 318 mm and greater than 60 mm from the head and foot panel. The headboard and footboard of the transfer device consider these values in their design.

5.3 Low weight structure

Although no weight analysis was performed on any design, concerns regarding the weight of the structure became clear when designing these devices. In the pursuit of developing a lite weight conveyer structure a solid and time tested design was found in the aeronautics industry. Aircraft wings possess simple components that wen assembled form a light but very rigid structure shown in Figure 43. The wing spar can be considered the main component of a wing structure since all other component attaches to it. It usually describe a “T” or “I” shaper. To form the wing spar a sheet aluminum is cut by CNC machines using laser cutting, water jets or punching dies. Lightning hole are made to reduce the overall weight of the structure. The sheet metal used for the spar is usually 3 times the thickness of the sheet metal used in the ribs. The resulting profile is then submitted to shape bending depending on the pretended shape a different die is used. Generally these dies do not handle bends greater then 90°.

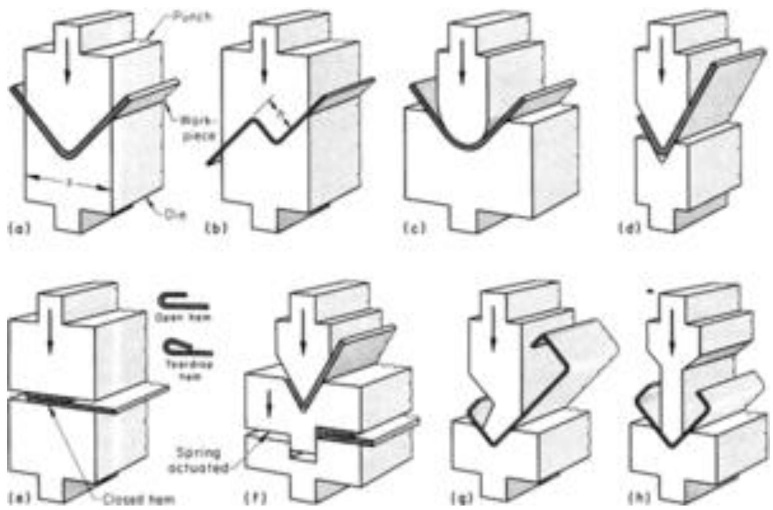


Figure 42 - Die bending [57]

The cut sheet metal profile process to obtain the ribs is similar to that of the spar but the rib obtains its final shape from a special set of dies. The profile is placed in a press between to metal and/or rubber dies that confer a special form to it. These dies can emboss and flange the ribs which are methods to add strength to a sheet metal part. As the material is deformed, the effective material thickness increases increasing its yield strength. The resulting shape can be seen in Figure 43. The description provided is one of several other also applicable to this subject but these are the features that will be utilized in this application.

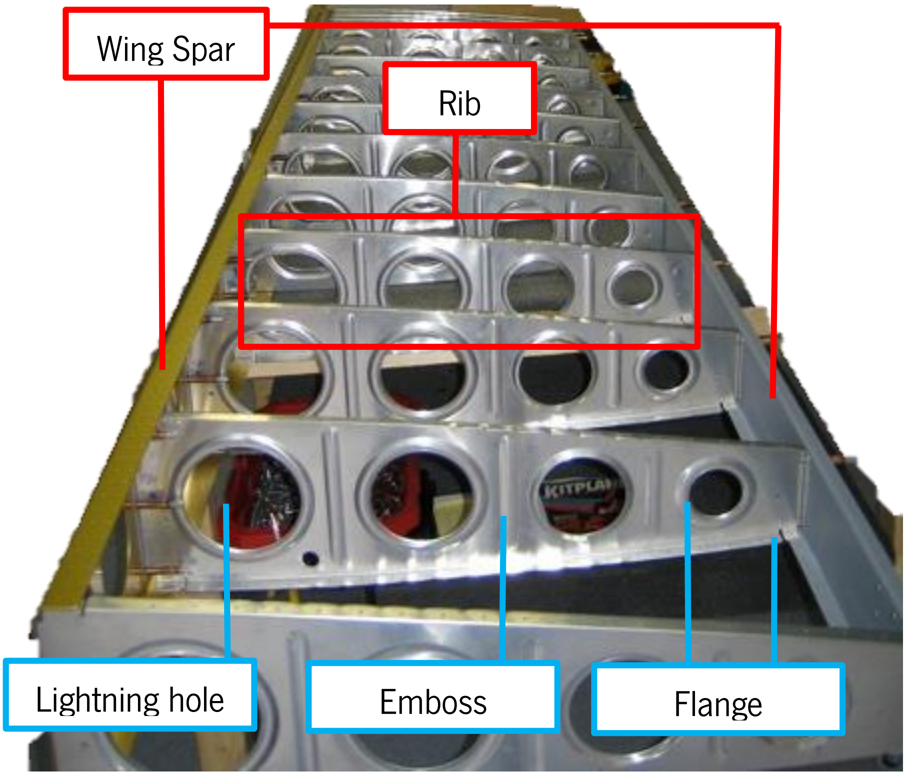


Figure 43 - Inner structure of an aircraft wing (adapted from [58])

Since actuators are limited to operate in a single direction, possess a limited stroke and have a large footprint and lack the necessary force to drive this particular application another the movement mechanism of the conveyer structure had to be rethought and the solution is presented in the following chapter. Figure 44 shows the render of 3D CAD model of the developed inner structure of each conveyor module.

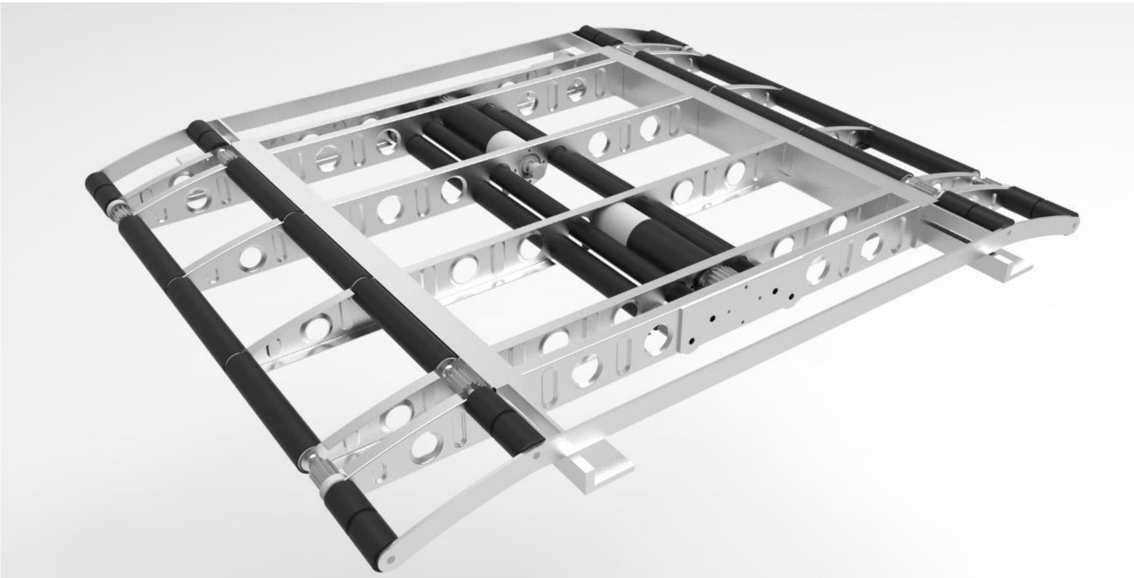


Figure 44 - Rendered conveyor modules inner structure.

5.4 Linear movement system by means of a crossed tensioned elements

The need for this system stemmed from an issue regarding a movement system that needed to move from both side from its base structure. Possessing a stroke equal to the length of the base without having any part of the structure interfering with the areas represented with the diagonal line pattern in Figure 45. On their own traditional mechanisms like Scotch yoke and even more modern like linear actuators could not perform without infringing the areas motioned or were limited in terms of range and direction.

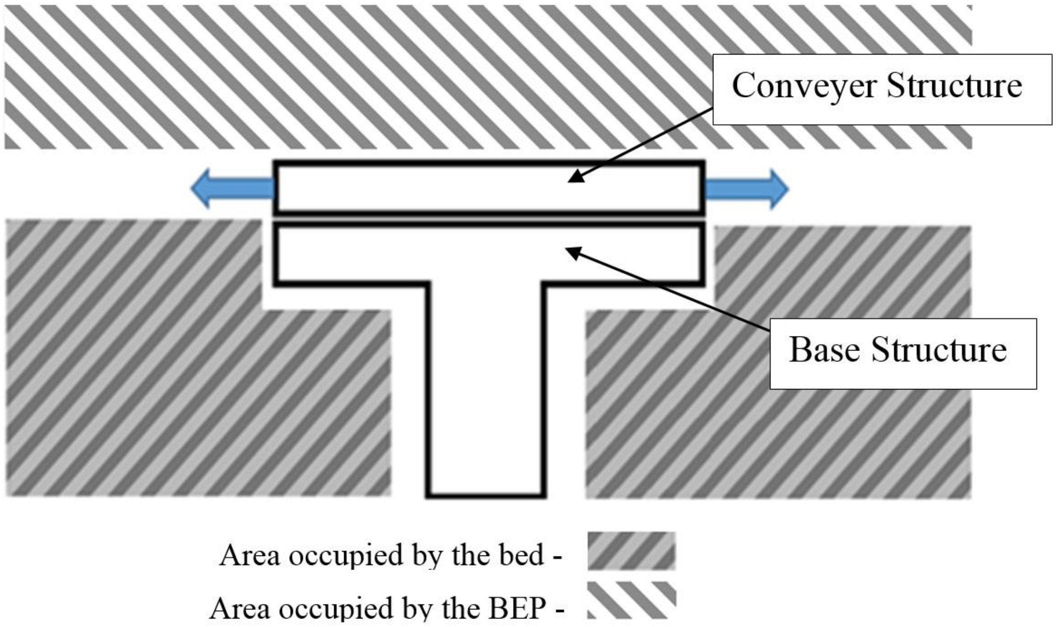


Figure 45 - Obstructed areas, front view.

This system is shown in Figure 46 and is composed of a base (**1**), a trolley[1] (**2**), a flexible element (belt, wire, cord, chain, etc.) (**3**), rails (**4**), bearings (**5**), tensioners (**6**), spools (**7**), a motor (**8**), gearbox (**9**) and shaft (**10**). The trolley is connected to the base by the rails; these rails restrain the movement in terms of the direction. The rails can be either fixed rails or telescopic rails. The system can extend to both sides of the base and the maximum stroke that it can provide is approximately the length of the base. This is due to the mechanical constrains of this particular system. These affirmations regarding the stroke are only true as long as no other mechanical constrain exist, for example, the stroke of a telescopic rail being inferior to the base length.

[1] Note: The trolley describe here is the Conveyer structure in the overall concept. The term trolley is used so that the conveyer structure elements are not mistaken for the one employed by this mechanism.

Therefore, when the system is fully extended (to either side) the overall maximum length is equal to two times the length of the base.

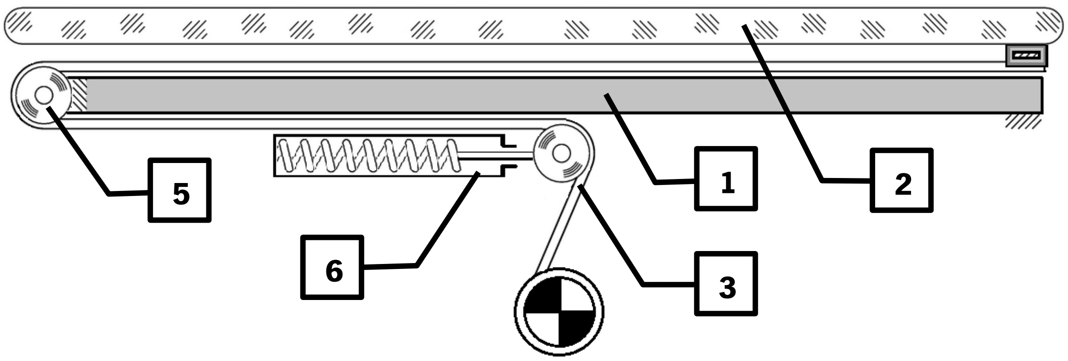


Figure 46 - Track

In this application, a “track” is the term given to a set of components that pulls the trolley (**2**) relative to the base (**1**). Figure 46 shows the composition of a track, note that the base (**1**) and trolley (**2**) are the same for all tracks and that the rails that connect them are not shown in order to offer a better visualization. Motion is provided by applying tension to the flexible element (**3**) bound to one of the sides of the trolley (**2**). The flexible element (**3**) is wrapped on a bearings (**5**) embedded in the base on the opposite side. A gap between the base and trolley is recommended, to accommodate the height of the flexible element (**3**) with enough clearance to avoid drag or friction. The flexible element (**3**) leaves the bearing, embedded in the base, to wrap around a pulley connected to tensioners (**6**) that are located underneath the base. The tensioner (**6**) is simply a pulley that apply tension and is adjustable by setting a screw to the desired tension. Ideally, tensioned pulley should be situated past the center of the structure in order to provide a greater wrap angle. Leaving the tensioners (**6**) pulley the flexible element (**3**) must wrap around the spools (**7**). This spools (**7**) as a groove in which the flexible element (**3**) can be attached and secured. Initially in order to increase the coefficient of friction the spool can also be wound a few turns of the flexible element (**3**). Figure 47 shows a pair of tracks overlapped on top of each other. Notice that the track that pulls the application to the left as its flexible element (**3**) been feed to the left of the spools (**7**) wrapping in a counter clockwise fashion. The track that pulls the application to the right as its flexible element (**3**) been feed to the right of the spools (**7**) wrapping in a clockwise fashion. These two tracks make a pair that crosses on top of one another. Together they insure movement by guarantying that when one tracks is pulling by wrapping the flexible element (**3**) in its spools (**7**) its pair is unwrapping its flexible element (**3**) and vice versa.

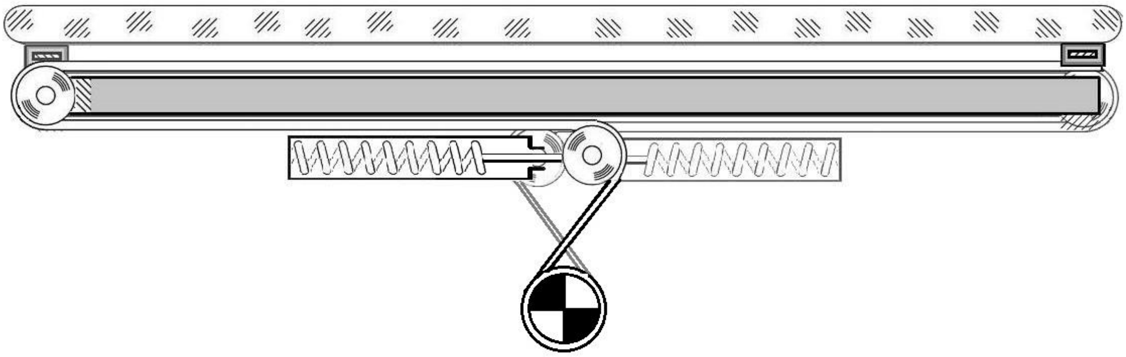


Figure 47 - Overlapped pair of tracks

This crossed configuration is the operating premise of this system. The solution may contain any number of pairs of tracks but ensure a proper movement at least two pairs are recommended. As long as the system is limited to a linear motion in the same direction of the tracks the number of pairs of tracks is a decision left to the individual implementing this solution on their design. Figure 48 shows an example with the proposed number (of two) pairs of tracks. All spools (**7**) are fixed to the same shaft (**10**) and motion is transmitted to this shaft by means of a single motor (**8**). Each spool (**7**) in pair "α" as its counterpart (group "A") in pair "β" (group "B").

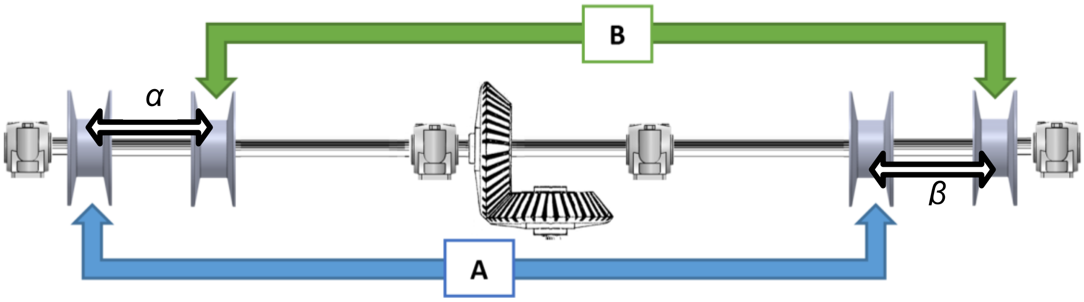


Figure 48 - Shaft layout

The motor (**8**) can be mounted in numerous configuration but for the limitation mentioned earlier and shown in Figure 49 a centered vertical motor (**8**), underneath the base (**1**), is the optimal choice (although the position may vary to accommodate for components placement). Although the term "gearbox" is applied most of these right angle gearbox (**9 - a**) have a reduction ratio of 1:1 so a second gearbox (**9 - b**) is recommended. Since speed is not an issue in the application that this system is intended a less powerful motor may be combined with a larger reduction value gearbox.

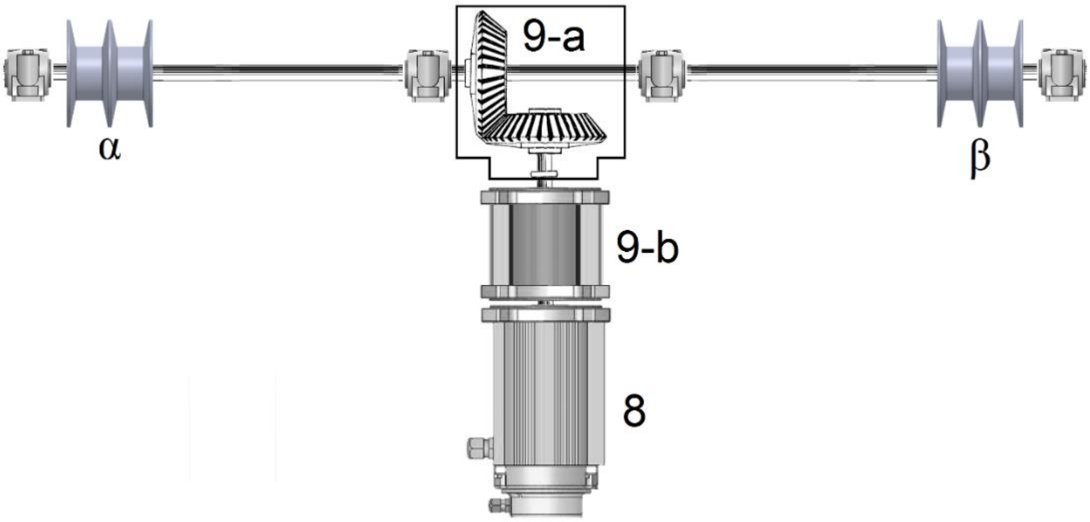


Figure 49 - single shaft right angle gearbox configuration

Figure 50 shows the implementations of this concept in the proposed transfer solutions. In the figure, the movement mechanism is shown with the trolley and the tensioned element so to provide a better look at the interworking's.

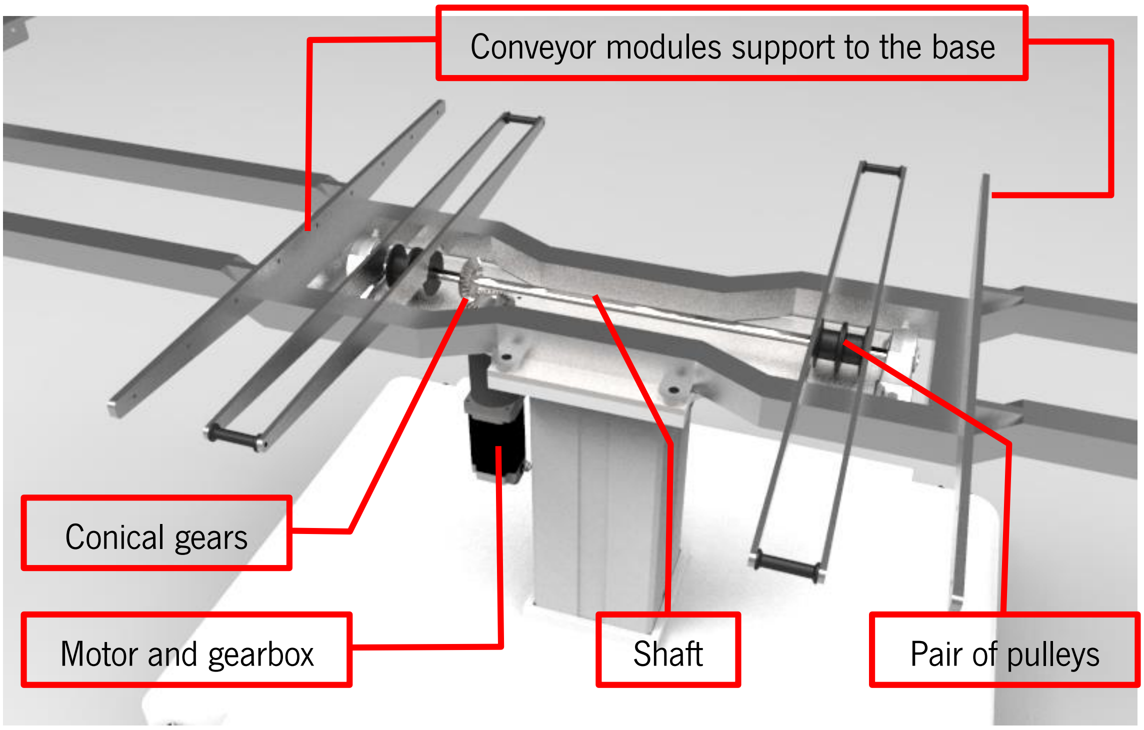


Figure 50 - Movement system 3D CAD rendering

5.4.1 **Movement mechanism demonstration**

Since this is a very compact system providing a CAD drawing to display the movement mechanism component did not provide satisfactory representation. So in order to demonstrate the operations performed by this mechanism a prototype at 1:3 scale as build. This also served as a proof of concept for a future build. The construction and components are very rudimentary available in any local hardware store. The trolley discussed in the previous chapter is in fact the conveyer module and is represented here by the grey model of the conveyer structure. The final aspect of the device can be seen in Figure 51.

Figure 51 - tensioned elements mechanism prototype, front view.

When the system is put into effect, the conveyer structure is shifted alongside the rails that simulate the extended telescopic rails. Figure 52 shows the conveyer shifted to the right and the tension element (cord) configurations wen in that position.

Figure 52 - tensioned elements mechanism prototype, shifted to the right

In Figure 53 a better view on the configuration of the tensioned element.

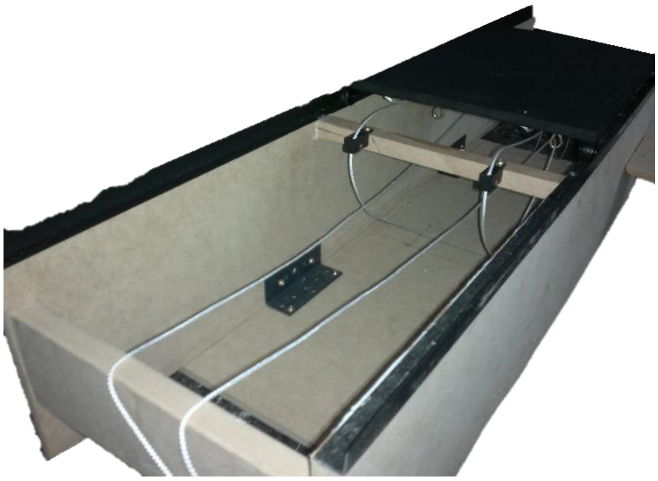


Figure 53 - tensioned elements mechanism prototype, wire view.

The electronic components for this prototype are shown in Figure 54. The code installed on the controller is available in Annex G. The controller is an Arduino Uno with an Atmega 328 microcontroller that sends the movement information to the stepper driver that controls a Nema 24 stepper motor. The stepper drive serves also another function which is the power management from the power supply since the tension value present in the Arduino board is not adequate to drive the motor. User input and motion control is provided by a numerical keypad.

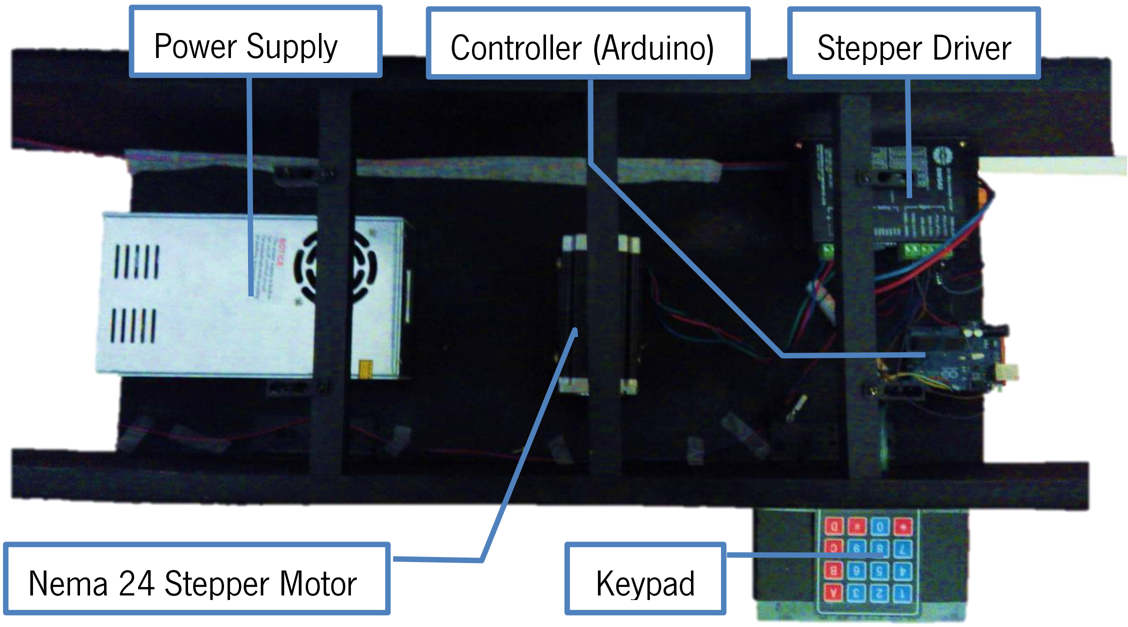


Figure 54 - tensioned elements mechanism prototype, electronic components.

5.5 Operational steps.

The following describes how the approach to retrieve and deposit the bedridden individual is performed. Before utilizing the transfer device it must be positioned to assure proper functions. To do so the transfer device must first be placed in parallel with the patient bed. Raise the conveyor modules so that their base plane is over the top plane of the mattress of the bed. Advance the transfer device so that its base is placed under the patient bed and the conveyor modules over it. This is done until either the side of bed is placed right next to the column on the base structure or the side of the conveyor modules is right next to the patient. The conveyor modules are then lowered by means of the elevating column until the base plane of conveyor modules is at the same plane with top of the bed mattress.

Following the procedure described in Figure 55 the conveyor modules advance in the directions of the patient until the side of the conveyor is right next to the patient. Now the conveyor modules advance while conferring rotation to the belt on the conveyor modules in the opposite direction. As soon as the patient is on the conveyor, modules retract them without conferring rotation. When the modules have returned to the base structure cease operations.

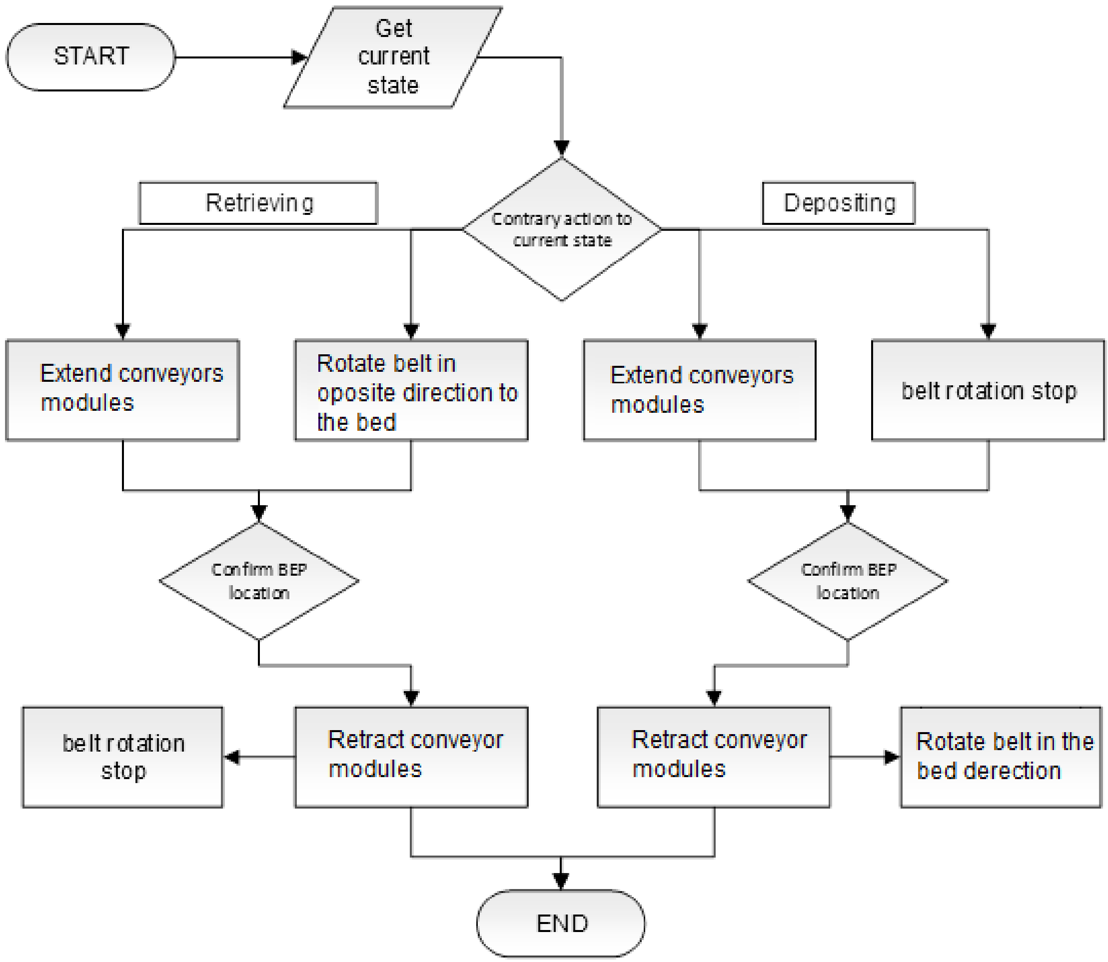


Figure 55 - Retrieve/ deposit patient process flowchart

What to retain from chapter 5

The final concept will employ a center driven conveyer belt by two opposed motors that will drive a timing belt attached to the conveyer belt. A structure similar to the one used for the wings in the aeronautics industry will be employed as a lightweight solution for the structure of concept. The gap issue will be resolved with a smaller belt actuated by the two adjacent belts. To extend and retrieve the conveyer modules a simple cabled system will be utilized.

Chapter 6

Solution development

This chapter describes in more detail the several components of the final solution. The structure configuration and construction is described in more detail. The selection process of the conveyer belt element, motors and actuator are shown. The developed algorithms and control structures shown will provide a basis to defined the control devices and selected the sensors needed. The user interface is also discussed and the chapter ends with a 3D simulation of the complete solution.

6.1 Belt and timing belt

A belt conveyor is set of components that in conjunction have the ability to move loads. These components are base frame, continuous belt, drive pulley and one or more sliding rollers. Along most of the area were the load travels the belt is supported by either a slide bed plate or rollers made of steel, wood or plastic. Several components such as pulley motor, drum motor or geared motor can transmit motion to the conveyer belt. In a conveyer design, the belt is the component that carries the load. These belts can be simple conveyer belts reeling on friction and tension between pulleys or timing belts that receive their power from gear. Conveyer belt are usually made of nylon, PVC, polyurethane, neoprene etc. The standards taken into consideration for calculation of power and tensile forces are the ISO 5048 and DIN 22101. The higher the wrap angle β that the belt makes on the drive pulley and the friction coefficient μ between belt and drive pulley the higher the resulting traction force applied to the belt. Snub pulleys are primarily used to increase the arc of contact at the driving pulley. This is so because for the use of only the conveyer belt a large wrap angle would be required to maintain tension in order to provide motion. Using the timing belt grants de ability to provide motion by the mechanical linkage between the timing belt and timing pulley teeth. What this also implies is that there is no slippage of the belt. As shown in Figure 56, some conveyer belts already implement this concept by providing a smooth surface to wrap around the structure and on that same surface provide two tracks of teeth thus making a timing belt.

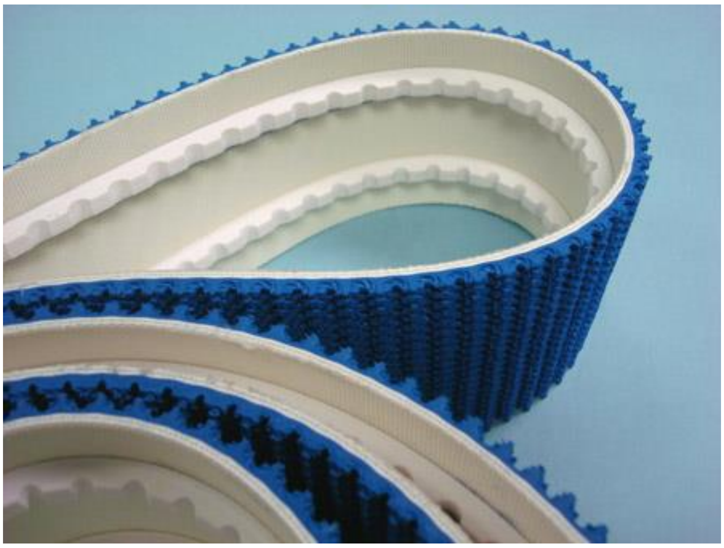


Figure 56 - Conveyor Belt Blue Ruff Top & V-guides (Adapted from: [59])

Therefore, what proposed here is using two taming belts attached to a continuous fabric belt. The timing belt will provide motion and the fabric belt will be were the load is transported. No standards were found that described the considerations and procedures for selecting a conveyor belt for the handling and transport of live human body's.

6.2 Nosebar and noseroller

Nosebar, also known as knife-edge, and noseroller are two components that can be attached to the end of a conveyer in order for the conveyer belt to wrap around the edge. A nosebar, shown Figure 57, is commonly a steel plate with one end rounded. A Nosebar with a radius of approximatively 3 mm / 0.12 in or less is typically referred to as a knife-edge. A noseroller is simply a roller with or without embedded bearings. The radius of the noseroller is dependent on the available bearing units and the maximum bending allowance by the belt material.

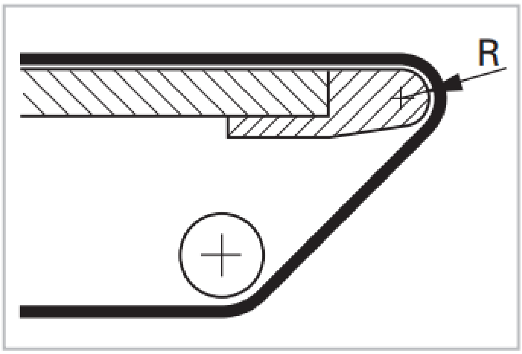


Figure 57 - Nosebar/knife-edge (Adapted from: [60])

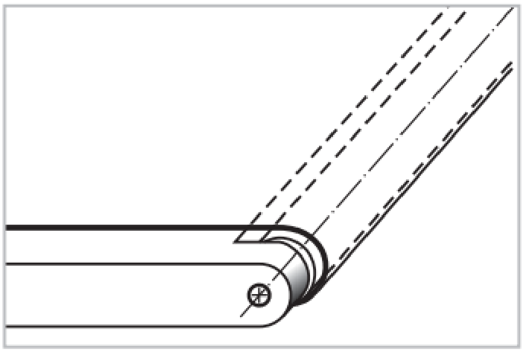


Figure 58 – Noseroller (Adapted from: [60])

Noserollers are preferred in application were friction is an issue that cannot be overcome by the motor. A typical noseroller setup is shown in Figure 59 were several narrow rollers are fitted instead of one continuous roller. The advantage here is that the shaft is supported at several points thereby reducing shaft deflection.

Figure 59 - Inner workings of an industrial conveyer noseroller (Adapted from: [61])

6.3 Rollers and slider bed

Flat slider bed, example on Figure 60, serve as a plane surface were the conveyer belt drags its load over. The slider bed can be made of several materials such as pickled steel sheet, stainless steel, plastics less commonly wood. Roller beds substitute the plane surface for a set of rollers that rotate as the load passes over them. The rollers possess a metal shaft that either as the roller material directly applied to it or as a set of bearings coated with the roller material. These rollers can be made of several materials depending on their intended pursue. Some of these are coated with a rubber that possess a high coefficient of friction. Others posse a padded materials such as cloth to either dampen sound or to handle fragile loads.

Figure 60 - Steel flat slider bed (adapted from: [62])

Figure 61 - Roller Bed (adapted from: [63])

For this application, a stainless steel sliding bed will be used. To factors dictate this choice, the first is due to the need to protect the interworking of the conveyer structure. Sensible equipment is present in inside this structure and since we are dealing with a human the risk if body fluids interacting with them is high. The second factor due to the rollers configuration that create an uneven surface, said surface my cause discomfort or injuries to the patient.

6.4 Telescopic rails

Telescopic rails serve as a mean to provide support wen the conveyer modules is extended beyond the base structure. They also provide the crucial alignment that is key for successful operations. Since anything that causes misalignment may cause degradation, misalignment forces the rolling elements (ball or roller) in the bearings or guides into an elliptical rather than spherical shape. The chosen components for this application are the DEF 35 and DEF 43 manufactured by ROLLON®. Two DEF 35 will provide support to the middle section conveyer module and two DEF 43 will support upper and lower sections at the head and feet. The length chose for all the telescopic rails was the 690 mm version. These components were chosen for their high load capacity and the fact that their stroke is greater than double their length and their ability to operate on both sides. The load in a pair of telescopic rails is applied to the center point between both guides, as shown in Figure 62. The following formula presents their combined load capacity:

$$P_1 = 2 \times C_{0rad} \qquad (6.1)$$

Figure 62 - Static load check (adapted from [64])

For two DEF 35 with a length of 690 mm this signifies that they both can handle a load applied to its center of 1468N (approximately 178 kg). As for the DEF 43 with a length of 690 mm can handle a total of 6182N (approximately 630 kg.).

6.5 Wheel Base

Precise alignment of the conveyer structure with the patient bed is crucial to ensure operations. Also due to the spatial constrains of the home setting this sort of devices requires a high maneuverability to avoid the risk of collisions. Fixed and free pivoting traditional wheels simply cannot perform complex maneuvers in an enclosed space. To solve this issue other types of movement and drive mechanisms were analyses:

– Swerve Drive – Are independently simple wheels steered and driven by independent drive modules. These devices have a high pushing force and good traction. Nevertheless, these types of drives are complex to build, program, and control.
– Omni Directional drive – Omni wheels are wheels on wheels. They have high maneuverability and fairly simple to implement but their required configurations makes them prone to slippage and reduced traction.

– Mecanum Drive – Provides high maneuverability and simple implementation and control. However, there is a trade-off of reduced traction when compared to traditional wheels due to their geometry. In addition, there is a high initial acquiring cost for these components.

Figure 63 - Swerve Drive [65]

Figure 64 - Omnidirectional drive [66]

Figure 65 - Mecanum Drive [67]

A mecanum drive system was selected due to its high maneuverability (as shown in Figure 65) and the simple control operations. The speed value of individual wheels or base frame by means of simple linear functions of its inputs, no trigonometry or root function are present in these operations. Therefore, control calculations are perform very quickly. Although it possess a low traction, due to the angled peripheral rollers, this is not an issue since no slopes are expected in the home setting.

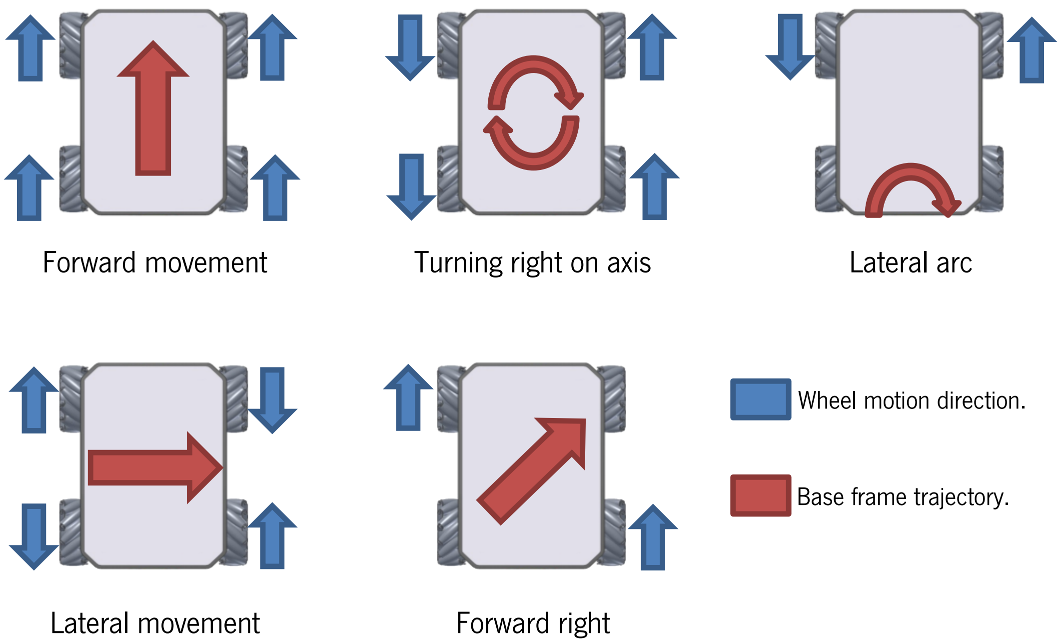


Figure 66 - Motion according to the direction of the device and angular speed of the wheels

The shape and configuration of the wheels transmit a portion of the force to the rotation of the wheel and another portion to a normal force perpendicular to the wheel. Considering a Cartesian coordinate system center to base frame, as show in Figure 67.

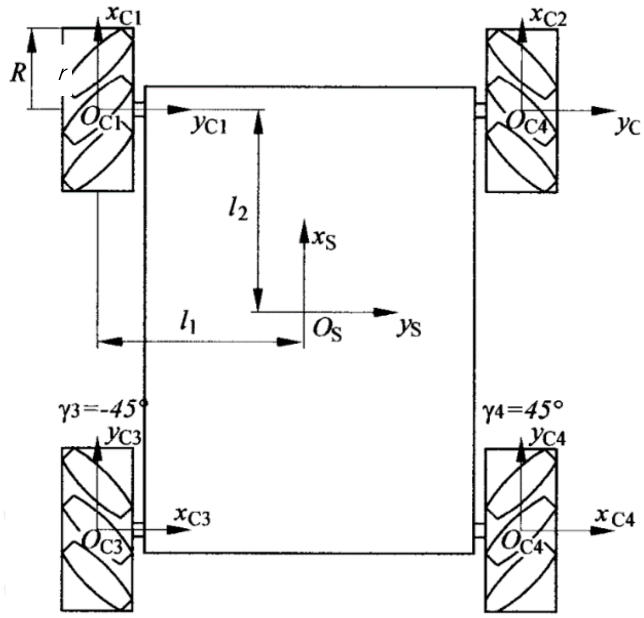


Figure 67 - Kinematics of the Base (Adapted from: [68])

The speed (v_x and v_y) and direction, provided by angular velocity (ω_z), of the base frame can be written as such:

$$\begin{bmatrix} v_x \\ v_y \\ \omega_z \end{bmatrix} = \frac{r}{4} \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & -1 & 1 \\ -\frac{1}{l_1 + l_2} & \frac{1}{l_1 + l_2} & -\frac{1}{l_1 + l_2} & \frac{1}{l_1 + l_2} \end{bmatrix} \times \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix}$$

Where:

- r is the radius of the wheels;
- ω_i is the angular velocity of the wheel i (i = 1..4);
- $l_1$and l_2 are the distances between wheel axis and the center axis of the base frame;

If on the other hand the speed and orientation of the base frame is provided the individual wheel speeds can be obtained by:

$$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} = \frac{1}{r} \begin{bmatrix} 1 & 1 & -(l_1 + l_2) \\ 1 & -1 & l_1 + l_2 \\ 1 & -1 & -(l_1 + l_2) \\ 1 & 1 & l_1 + l_2 \end{bmatrix} \times \begin{bmatrix} v_x \\ v_y \\ \omega_z \end{bmatrix}$$

6.6 Motion mechanisms

This solution requires several motion mechanisms in order to perform its tasks. Several types of actuators were used to perform those required motion next is shown the challenges found and the solution adopted

6.6.1 **Elevating column**

When the device approach the bed of the patient, it may not be at the same height of the device. So to correct the difference an elevating column is used. The component choses was the SKF TLG10 – AA31A – 000. From the components available only the ones developed specifically for medical applications were considered. These all possess the EN/IEC 60601–1 revision of the of technical standards for the safety and effectiveness of medical electrical equipment. This particular model was selected because it was rated for maximum push load t, which is the load that hat the device can lift, of 4000 N.

Figure 68 - SKF TLG10

6.6.2 **Belt motor drive**

As shown in Figure 69 a central motor drives a timing pulley that wrap around several other smaller timing pulley to describe the path performed by the conveyor belt.

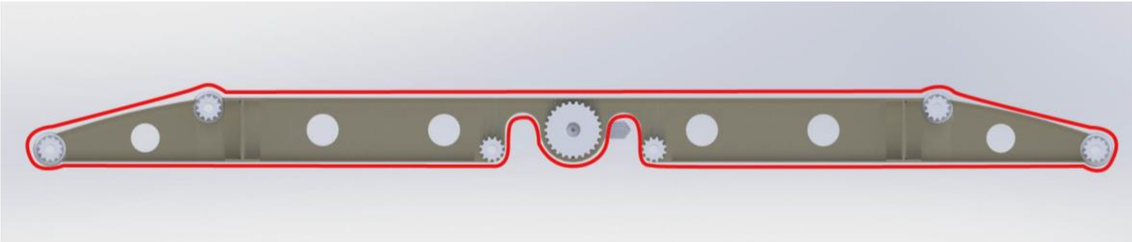


Figure 69 - Timing belt path around the structure.

The mass m to be carried by 81.38 kg that corresponds to what was previously established as the max load on a conveyor module. The maximum allows speed is 0.25 m/s. The coefficient of friction between the smooth steel surfaces and the fabric of the conveyor belt is μ = 0.1. The drive pulley radius is 20 mm. By summation of the forces involved:

$$\sum \vec{F} = F_u + F_r + F_a \tag{6.2}$$

$$F_u = F_r + m \times \frac{dv}{dt} \tag{6.3}$$

Thus the Effective pull F_u is 80,51 N. To obtain torque T the following formula is applied:

$$T = F_u \times r \tag{6.4}$$

Thus the required torque for one motor to rive this belt is 16,1 Nm. Two motors can be combined to double the output but if this is not done correctly, several issues may occur. One of these issues is that the workload distribution would not occur and one motor may end up performing all the work while the other will only aggravate the workload. To avoid these issues quality motors and feedback components must be utilized. The motor and gearbox selected are produced by maxonmotors. The motor seen in Figure 70 is the EC-i 40 Ø40 mm, brushless, 100 Watt, with Hall sensors. The gearbox, seen in Figure 71, selected is Planetary Gearhead GP 42 C Ø42 mm, 3 - 15 Nm, Ceramic Version

Figure 70 - EC-i 40 Ø40 mm, brushless motor from Maxonmotor (adapted from: [69]**)**

Figure 71 - Planetary Gearhead GP 42 C Ø42 mm, 3 - 15 Nm, Ceramic Version (adapted from: [69]**)**

These were selected since their combinations offers a high torque value for such small components. The maximum combined output of this configuration is 30 Nm per conveyor module (set of two motors and gearhead) which exceeds the required calculated torque of 16.1 Nm.

6.7 Control operations

Medical equipment need to stand up to conditions that are not expected from normal devices such as corrosive substances. The control system that are sold in conjunction with the actuators and other equipment designed for healthcare tend to be enclosed regarding its interworking's. Other devices are more open to development such as microcontrollers or microprocessor boards but on their own sensible to corrosion, impact and EMF. For a controller the use of a PLC is best suited for this sort of application since these devices are submitted to extremely hazardous conditions. Since PLC's are built to provide a better insulation from exterior influences like EMS, temperatures, humidity and dust the control operations are more reliable. It does this by providing a physically isolation separating its inputs/outputs from internal and external components. PLC's posses their own standard IEC 61131-3. Some PLC's are designed for the healthcare industry. These must be IEC 60601-1-11:2015 compliant to handle EMI interference and EMS for the home environment and IEC 60601-1-12 compliant to operate in the professional setting. The other reason the choice of a PLC over the simple controllers that can be acquired in conjunction with the actuators and motors is the need for input/output of signals. These signals can be simple on/off signals, serial communication such as CAN, I²C SPI, SSI, RS-232 or even more high-end communication protocol such as TCP/IP. Figure 72 shows a simple diagram describing the connections between components (Actuators, motors, drives, batteries) which interact with the PLC. The PLC acts as the controller for these applications but receives its commands via a remote control. This remote possesses inputs for all the necessary commands as well as a 3-Axis joystick to operate the mecanum wheels located in the base of the solution. These wheels and the conveyor servo motors are controlled through the PLC by a servo drive that handles the servo motor operations and the feedback from the encoders. The Telescopic pillar that adjust the height of the Conveyor structures is controlled trough the PLC via its own control unit. Power can either be provided through the battery pack or directly by a mains outlet. The motor with a right angle gearbox is used to drive the custom movement system by means of a crossed tensioned elements. The control of the device can either be performed by a GUI (Graphical User Interface) on a mobile device or by the developed ergonomic control remote. Figure 72 shows the relations between the components and the connections between them.

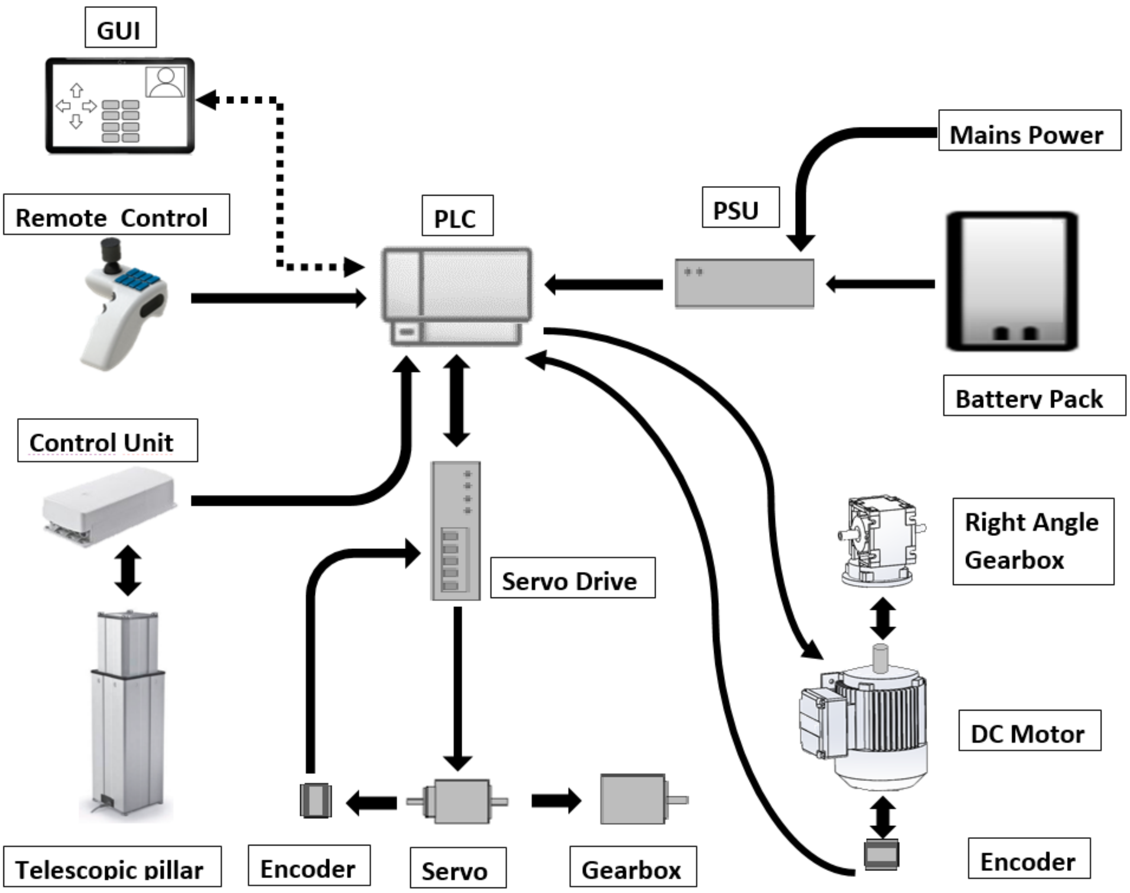


Figure 72 - Component connections diagram

The use case seen in Figure 73 describes the actors that interact with the device. In this application the user only controls the elevating column rise and descend, the advance/retraction of the conveyor modules from and the advance/retraction of the conveyor modules while the belts rotate.

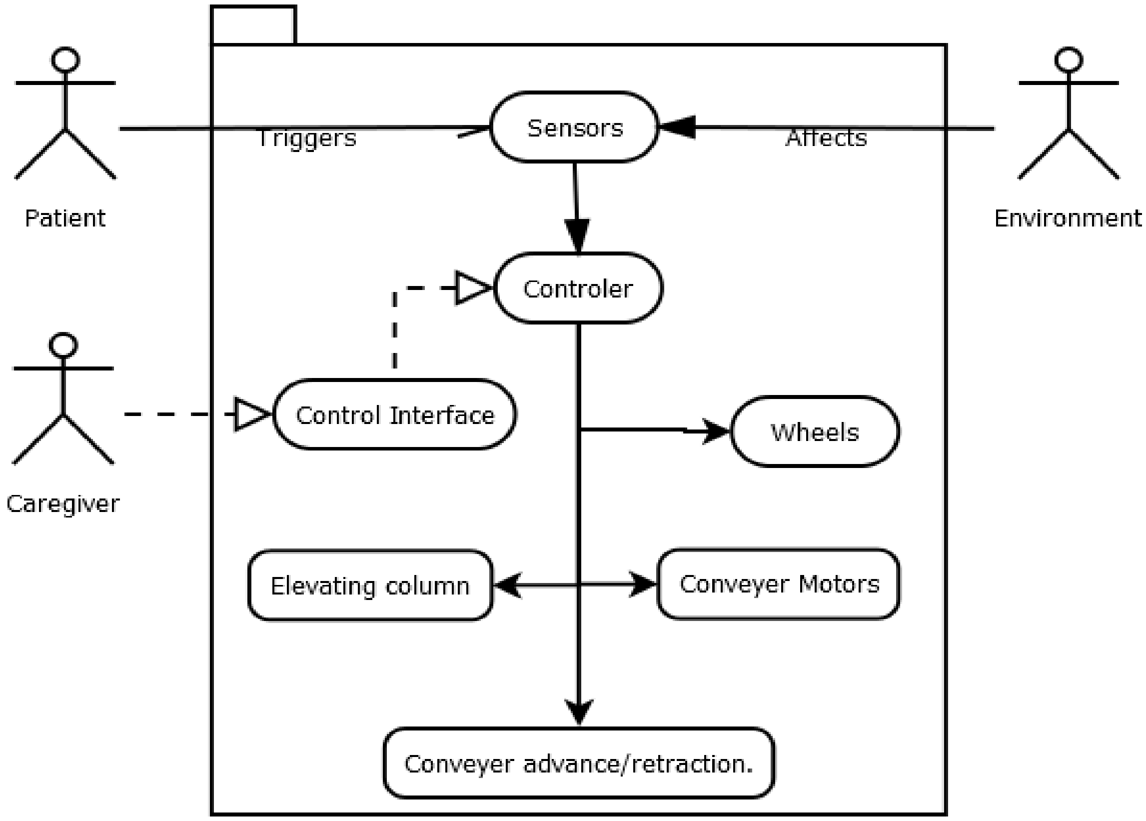


Figure 73 - User case

6.8 Sensors

This device possess several automated processes and these require some feedback to guaranty proper operations. Precautions must be taken into account in order to protect the patients of this applications. The device must possess means to obtain information from its environment and the actors involved. The controller receives its feedback through means of transducers that converts an input energy in another form (generally electric) so that its output may be measured.

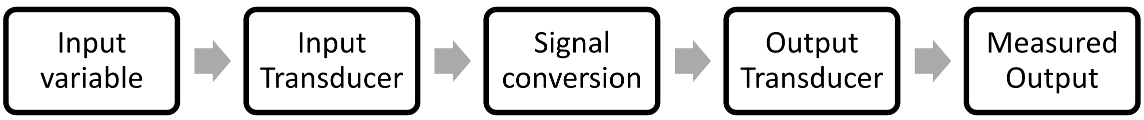


Table 5 - Sensors, Inputs & Outputs

Input Parameter	Input Sensor	Output data
Patient detection on the conveyor modules	Force sensing resistor	Tension variation value
Elevating column height	Potentiometer	
Bed presence under the conveyor modules	Photoelectric or ultrasonic distance sensor *	Boolean Value (On/Off signal)
Max extension of the conveyor modules	End-stop or opto-switch	
Bed lateral contact with elevating column	Mechanical contact detection bumper	
Conveyor modules in "home" positon.	Inductive or capacitive sensor *	
Movement mechanism speed	Encoder	Speed value
Base mecanum wheels speed		
Belt rotation speed		

* Type of sensors was not defined since the conditions for input was not bound to specific criteria.

6.8.1 Encoder

The encoder is a crucial sensor that gives the system a return value to be interpreted. Thanks to this device and through some logics operations, speed and position can be obtained. The encoder can be of two types, absolute or incremental and may have a digital or analog output. Its operating principle magnetic, optical, mechanical, capacitive or inductive. These devices would be coupled to the motors that drive the mecanum wheels so feedback can be obtained to ensure that the required movement are performed and if not a value to correct this error.

6.8.2 Load presence detection

A force resistor can be used to determinate if the patient is still on the bed. After retrieving the patient the sensor is aware of the presence of a "load" and if this load disappears without the deposit operation being perform can sound an alarm. Force sensing resistor or simply FSR are resistive sensors that changes their resistance value (ohms Ω) wen compressed. The FSR chosen for this applications is the Interlink model 408 FSR, shown in Figure 74. This particular model as a length of 609.6mm width of 10.2mm with a thickness of 0.41mm and is a single-zone force-sensing resistor.

Figure 74 - Interlink model 408 FSR

This means that it cannot tell were force is being applied but can tell how much within its load rating. Ideally single strips of FSR would not be utilize, instead a matrix of several FSR cell would create a mesh of sensors that could not only measure but also locate were pressure is applied. The problem with that approach is its complexity and cost and for this application, there is no need for that level of detail. Instead it is proposed to apply only tree strips of Interlink 408 FSR strips in an diagonal configuration as shown in Figure 75. Their length and thickness make these particular sensors perfect for this application

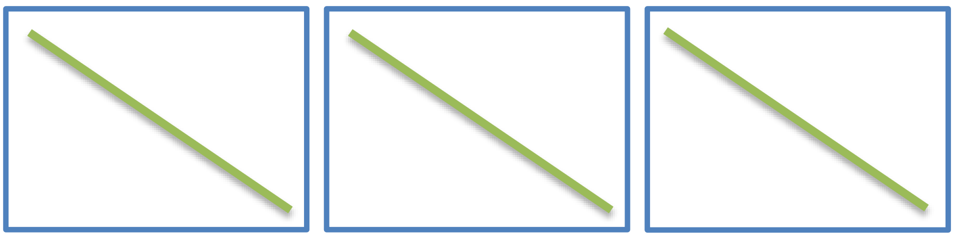


Figure 75 - Distribution of the FSR strip on the conveyor modules

To obtain a voltage value that varies with the load the FSR must be configured as shown in Figure 76.

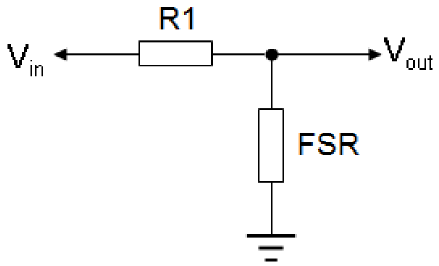


Figure 76 - FSR location on a resistive voltage divider circuit

Equation (6.5) describes the relation between V_{in} and V_{out} in a voltage divider.

$$V_{out} = \frac{FSR}{(FSR + R_1)} \times V_{in} \quad (6.5)$$

6.8.3 **Bed detection sensor**

Several sets of light or mechanical sensors can be utilize to know if the device is totally extended or if in alignment with the base structure. These sensors can be photo resistor or photodiode or an simple end stop.

6.9 User Interface

The control of any application requires a device through which information can be passed from the user to the controller device of the application. Regular hospital beds use remotes similar to the one shown in Figure 77. As for the control of the mecanum wheel setup what used in the robotics industry is a multi-axis joystick similar to the on seen in Figure 78. This special joystick is required to control of three degrees of freedom are required.

Figure 77 - Hand switch HS (Adapted from: [70])

Figure 78 - Analog 3-Axis Joystick (Adapted from: [71])

Figure 79 shows the designed ergonomic controller that combines the two devices above into one seamless design. The three Axis Joystick enables the omnidirectional control of the mecanum wheels in the base structure while the control buttons each conttol one of the operations of the transfer system. The ergonomic shape of the controller enable the user to hold the controller in its left hands with ease. No operation occurs while the user does not press the safety switch the enables the other control options.

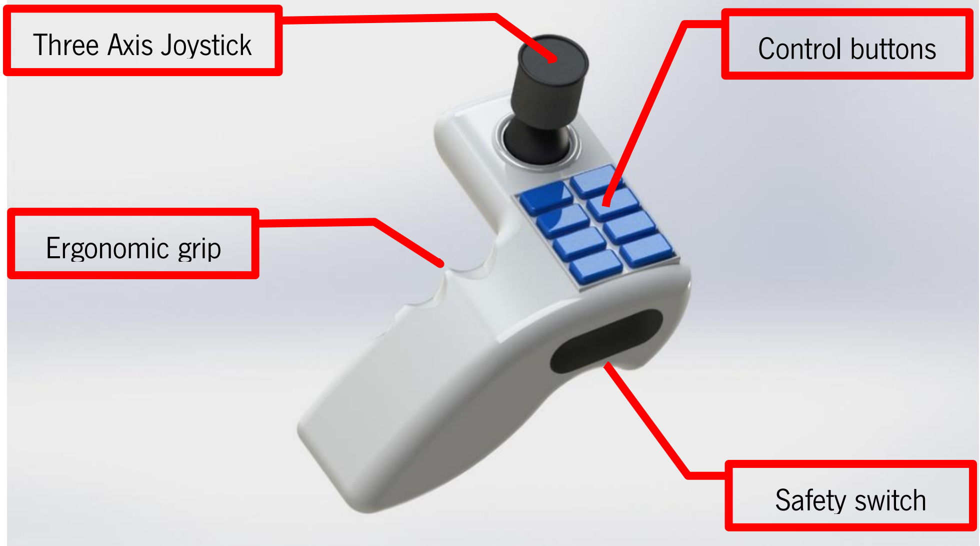


Figure 79 - Ergonomic remote with three Axis joystick

With today's variety of mobile devices, the use of a GUI to control the transfer device is well with reason. The development of such a device is beyond the scoop of this work but its implementations corresponds to a virtualization of the ergonomic controller described here.

What to retain from chapter 6

Chapter 6 provided a better description of the several components present in the final applications as well as others that could also be implemented. The interworking of the device were shown throughout this chapter. The control component were discussed in detail as well as the several transducer that provide feedback. For these operations the possible feedback devices, sensors, presented and discussed. To provide a better user interface an ergonomic controller was developed.

Chapter 7

Conclusions

This chapter will offer an assessment of the work performed in this dissertation by examining the presented results. It will also determine if the proposed objectives were met and draw corresponding conclusions. To end with a brief analysis on what can be developed in the following works.

Product development is time consuming and requires the usage of knowledge of multiple areas of study. Consequently, the development process was accompanied with a steep learning curve. During the work described in this dissertation, four concepts, with different operational methods, were studied. By means of a quantitative technique these concepts were compared and ranked and the developed design concept was chosen that was the basis for the solution presented in the previous chapter. The resulting final design solution facilitates the daily routine of the BEP by solving the main issues mentioned as the outlined objectives for this dissertation. Without compromising the patients comfort and wellbeing of the proposed solution is able to help with the transference of the patient from the device to another surface. It is also capable of directly transfer the patient from one bed onto another without intermediate steps that could cause discomfort. The mobility of the entire device is greatly enhanced by the mechanical properties of its wheelbase. What this enables is a more capable solution to move in locations where handling space is an issue. Before this work, few approached provided an in-depth knowledge specifically aimed for the development of this sort of applications. After reading this dissertation, the reader now possess a framework of the actors and requirements involved in the development of an AAL solution to reduce caregivers physical stress wen handling BEP. Additionally issues and constrains that may have not seam apparent are covered in-depth with detailed explanation and, when determined, even a possible solutions.

Although the device assists with the BEP ADL's it does no due so in the optimal way, as such further work is required in order to optimize its performance and reliability.

Future Work

Additional development will require a larger multidisciplinary team to further advance the mechanical design, component/material selection and software development. Further reduction to the thickness of the conveyer structure must be performed without compromising structural integrity and operational capability. During normal operation of the device, the center of mass of the device plus patient is ever changing. As such, concerns with stability may become an issue, so further study should be performed in order to ensure safety. As stated no current regulating norm exists that defines a belt material appropriate to handle a live human body, as such further development of an appropriate belt for this purpose must be performed. Exposed wires, such as the control pad cable, are prone to damage as the movement from the structure and motions associated with it can cause damage to them. The solution would be either to embed the controller pad with a wireless communication module or to develop an application that would grant control of the solution trough a mobile device. Such a controller should be developed taking into account the implementation of future AAL standards. Another desirable safety features is the ability of the device to predict if the patient not in risk of fallowing from the device. The basis are in place for a possible reconfiguration of the solution to one that has the ability to morph between a transfer bed and a wheelchair. The current solution requires de supervision and control by a person to perform its operation but the complete or partial automation of the process are desirable.

The final logical step is the production of a physical prototype to test in a real world situation if this application is viable. Proven its viability the device is ready for its distribution to the public.

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Annex A – Dimension of British Adults

Table II Dimensions of British adults

	Men Percentiles			Women Percentiles			
	5th	50th	95th	5th	50th	95th	
Standing							
1 Stature	1625	1740	1855	1505	1610	1710	95th: minimum floor to roof clearance; allow for shoes and headgear in appropriate situations
2 Eye height	1515	1630	1745	1405	1505	1610	50th: height of visual devices, notices, etc.
3 Shoulder height	1315	1425	1535	1215	1310	1405	5th: height for maximum forward reach controls worktop height (see para. 302)
4 Elbow height	1005	1090	1180	930	1005	1085	controls worktop height (see para. 302)
5 Hand (knuckle) height	690	755	825	660	720	780	95th: maximum height of grasp points for lifting
6 Reach upwards	1925	2060	2190	1790	1905	2020	5th: maximum height of controls; subtract 40 mm to allow for full grasp
Sitting							
7 Height above seat level	850	910	965	795	850	910	95th: minimum seat to roof clearance; may need to allow for headgear
8 Eye height above seat level	735	790	845	685	740	795	50th: height of visual devices above seat level
9 Shoulder height above seat level	540	595	645	505	555	610	50th: height above seat level for maximum forward reach
10 Length from elbow to fingertip	440	475	510	400	430	460	50th: easy reach forward at table height
11 Elbow above seat level	195	245	295	185	235	280	50th: height above seat of armrests or desk tops
12 Thigh clearance	135	160	185	125	155	180	95th: space under tables
13 Top of knees, height above floor	490	545	595	455	500	540	95th: clearance under tables above floor or footrest
14 Popliteal height	395	440	490	355	400	445	50th: height of seat above floor or footrest
15 Front of abdomen to front of knees	253	325	395	245	315	385	95th: minimum forward clearance at thigh level from front of body or from obstruction, e.g. desktop
16 Buttock – popliteal length	440	495	550	435	480	530	5th: length of seat surface from backrest to front edge
17 Rear of buttocks to front of knees	540	595	645	520	570	620	95th: minimum forward clearance from seat back at height for highest seating posture
18 Extended leg length	985	1070	1160	875	965	1055	5th (less than): maximum distance of foot controls, footrest, etc. from seat back
19 Seat width	310	360	405	310	370	435	95th: width of seats, minimum distance between armrests
Sitting and standing							
20 Forward grip reach	720	780	835	650	705	755	5th: maximum comfortable forward reach at shoulder level
21 Fingertip span	1655	1790	1925	1490	1605	1725	5th: limits of lateral fingertip reach, subtract 130 mm to allow for full grasp
22 Width over elbows akimbo	865	945	1020	780	850	920	95th: lateral clearance in workspace
23 Shoulder width	420	465	510	355	395	435	95th: minimum lateral clearance in workspace above waist
24 Chest or bust depth	215	250	285	210	250	295	
25 Abdominal depth	220	270	320	205	255	305	

Annex B - Cumulative Percent Distribution of Population by Height and Sex.

Height	Males						Females					
	20–29 years	30–39 years	40–49 years	50–59 years	60–69 years	70–79 years	20–29 years	30–39 years	40–49 years	50–59 years	60–69 years	70–79 years
Percent under—												
4'10"	–	–	–	(B)	–	–	–	[1] 1.7	–	[1] 1.0	–	[1] 3.3
4'11"	–	–	–	(B)	(B)	–	[1] 2.6	3.1	[1] 1.6	2.1	[1] 3.6	8.7
5'	(B)	–	–	(B)	(B)	–	5.7	6.0	5.0	8.0	9.0	16.0
5'1"	(B)	(B)	(B)	(B)	[1] 0.4	(B)	12.3	11.6	10.8	16.7	14.7	26.0
5'2"	(B)	(B)	(B)	(B)	(B)	(B)	20.8	19.7	19.8	23.3	23.4	36.9
5'3"	(B)	[1] 3.1	[1] 1.9	(B)	[1] 2.3	(B)	30.4	31.3	30.8	36.3	38.4	51.9
5'4"	3.7	[1] 4.4	3.8	[1] 4.3	4.4	5.8	43.5	46.6	46.0	50.7	52.8	69.9
5'5"	7.2	6.7	5.6	7.6	7.8	12.8	54.1	61.2	58.0	68.4	66.6	82.8
5'6"	11.6	13.1	9.8	12.2	14.7	23.0	72.4	74.0	72.2	79.7	83.3	89.3
5'7"	20.6	19.6	19.4	18.6	23.7	35.1	82.3	84.9	83.0	88.4	93.3	95.4
5'8"	33.1	32.2	30.3	30.3	37.7	47.7	90.3	91.8	91.2	95.2	97.0	98.4
5'9"	42.2	45.4	40.4	41.2	50.2	60.3	94.1	96.1	94.7	97.3	97.8	99.6
5'10"	58.6	58.1	54.4	54.3	65.2	75.2	97.6	98.9	97.8	98.9	99.6	99.6
5'11"	70.7	69.4	69.6	70.0	75.0	85.8	99.6	98.9	99.4	100.0	99.8	100.0
6'	79.9	78.5	79.1	81.2	84.3	91.0	100.0	99.4	99.5	100.0	99.9	100.0
6'1"	89.0	89.0	87.4	91.6	93.6	94.9	100.0	99.9	99.5	100.0	99.9	100.0
6'2"	94.1	94.0	92.5	93.7	97.8	98.6	100.0	100.0	99.5	100.0	100.0	100.0
6'3"	98.3	95.8	97.7	96.6	99.9	100.0	100.0	100.0	99.5	100.0	100.0	100.0
6'4"	100.0	97.6	99.0	99.5	100.0	100.0	100.0	100.0	99.5	100.0	100.0	100.0
6'5"	100.0	99.4	99.4	99.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
6'6"	100.0	99.5	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source U.S. National Center for health Statistics, unpublished data,

<http://www.cdc.gov/nchs/nhanes.htm>

Annex C - Cumulative percent distribution of populations by weight and sex (2007 – 2008)

Weight	Males						Females					
	20-29 years	30-39 years	40-49 years	50-59 years	60-69 years	70-79 years	20-29 years	30-39 years	40-49 years	50-59 years	60-69 years	70-79 years
Percent under												
100 pounds	-	-	(B)	(B)	-	-	\1 2.0	1,3	(B)	\1 0.4	0,2	(B)
110 pounds	(B)	-	(B)	(B)	(B)	(B)	4,9	4,7	3,7	\1 4.0	(B)	6,1
120 pounds	(B)	(B)	(B)	\1 1.1	(B)	1,5	16,3	10,5	7,8	7,9	7,2	12,4
130 pounds	4,3	\1 2.1	\1 2.5	\1 2.3	2,8	3,5	27,8	18,9	16,0	17,1	13,5	22,5
140 pounds	11,1	6,4	4,7	5,6	5,3	5,2	39,4	29,8	26,4	27,3	27,4	30,1
150 pounds	20,9	11,5	7,6	8,6	10,0	9,7	49,7	40,6	37,5	38,7	37,4	43,1
160 pounds	31,3	20,4	15,1	13,9	16,5	17,7	57,5	51,1	49,8	49,7	46,1	53,7
170 pounds	43,6	30,5	21,3	22,0	24,9	27,4	63,2	59,8	59,3	56,9	58,9	65,6
180 pounds	55,7	40,9	33,6	33,2	33,4	40,1	72,6	68,7	65,6	63,7	72,4	74,0
190 pounds	65,0	50,6	43,7	44,5	42,6	50,1	76,3	73,6	75,0	70,3	79,4	81,2
200 pounds	73,5	59,3	58,0	55,7	55,5	65,7	80,0	79,4	80,0	75,3	84,6	87,3
210 pounds	79,4	70,0	66,2	64,6	64,4	71,6	82,8	83,7	82,8	81,9	88,4	90,5
220 pounds	83,8	76,1	75,6	74,0	73,4	80,0	84,9	89,0	87,2	85,9	91,1	93,4
230 pounds	86,5	81,7	84,6	78,8	81,2	83,5	88,6	91,3	90,6	89,5	93,7	96,4
240 pounds	89,7	85,5	88,1	85,6	85,1	87,3	90,0	94,1	93,0	91,4	95,6	97,0
250 pounds	93,2	89,6	89,7	88,0	88,2	90,6	92,3	95,2	95,5	92,9	96,7	98,4
260 pounds	94,7	92,0	92,8	91,3	90,7	93,1	93,3	95,8	96,7	96,5	97,6	98,6
270 pounds	95,1	93,3	94,6	93,5	93,0	96,4	95,7	96,4	97,5	97,2	98,0	98,6
280 pounds	96,1	95,1	95,4	94,2	94,8	97,5	97,0	97,2	97,8	98,2	99,0	99,4
290 pounds	96,8	96,4	96,4	95,8	97,2	98,5	97,2	97,5	98,2	98,9	99,0	99,6
300 pounds	97,5	96,9	98,1	98,1	97,8	99,4	97,7	98,4	98,3	99,4	99,3	100,0
320 pounds	98,1	98,2	98,8	99,0	98,5	99,4	98,9	99,1	98,7	99,7	99,9	100,0
340 pounds	99,5	98,8	98,8	99,1	99,0	100,0	99,6	99,5	99,4	99,8	99,9	100,0
360 pounds	99,5	99,4	99,3	99,8	99,0	100,0	99,6	99,7	99,8	99,9	99,9	100,0
380 pounds	99,7	99,7	99,5	99,8	99,1	100,0	99,6	99,9	99,8	100,0	100,0	100,0
400 pounds	99,7	99,7	99,5	99,9	99,5	100,0	99,6	100,0	99,8	100,0	100,0	100,0
420 pounds	99,7	99,7	99,5	100,0	99,5	100,0	99,6	100,0	99,9	100,0	100,0	100,0
440 pounds	99,8	99,9	99,5	100,0	99,5	100,0	99,6	100,0	100,0	100,0	100,0	100,0

Source U.S. National Center for health Statistics, unpublished data, <http://www.cdc.gov/nchs/nhanes.htm>

Annex D – NSK procedure to select ball screw

B-1-4 Procedures to Select Ball Screw

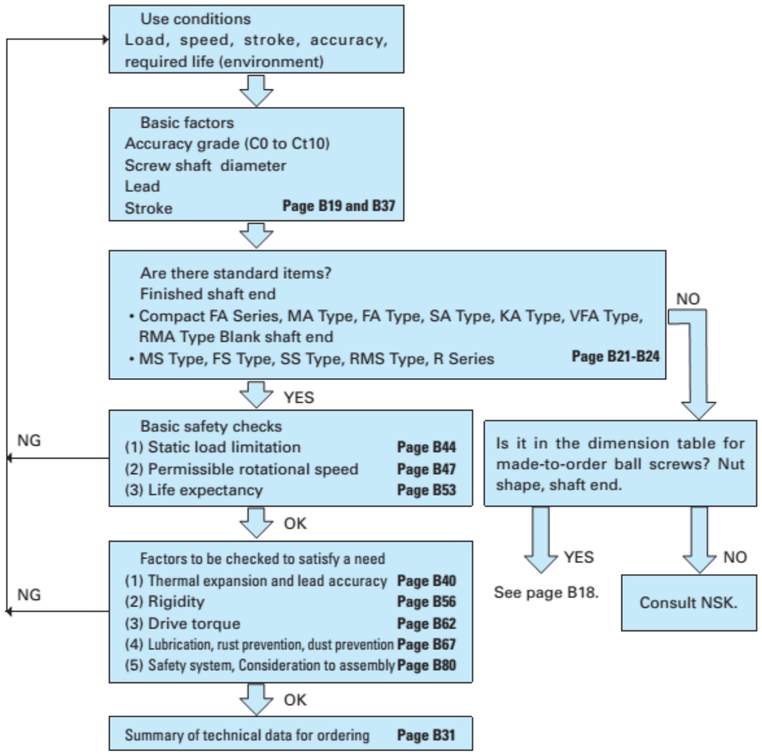
B-1-4.1 Flow Chart for Selection

When selecting a ball screw, you have to review a variety of use conditions and requirements such as applied loads, speeds, motion strokes, positioning accuracy, required life and operating environment. You require a multiple inspection because some of these conditions force a ball screw to have conflicting characteristics.

(1) Standard ball screw

The chart below is one of the selection procedures. To take advantage of prompt delivery and reasonable prices, this procedure focuses on the standardized ball screws.

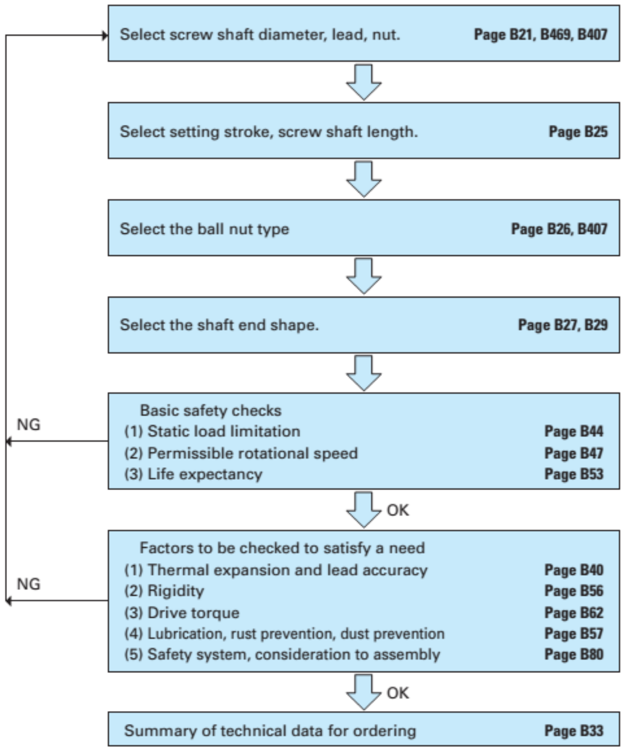
NSK offers a ball screw selection program, and also has a service to select appropriate items using data file compiled by our knowledge and experience.



(2) Made-to-order ball screws

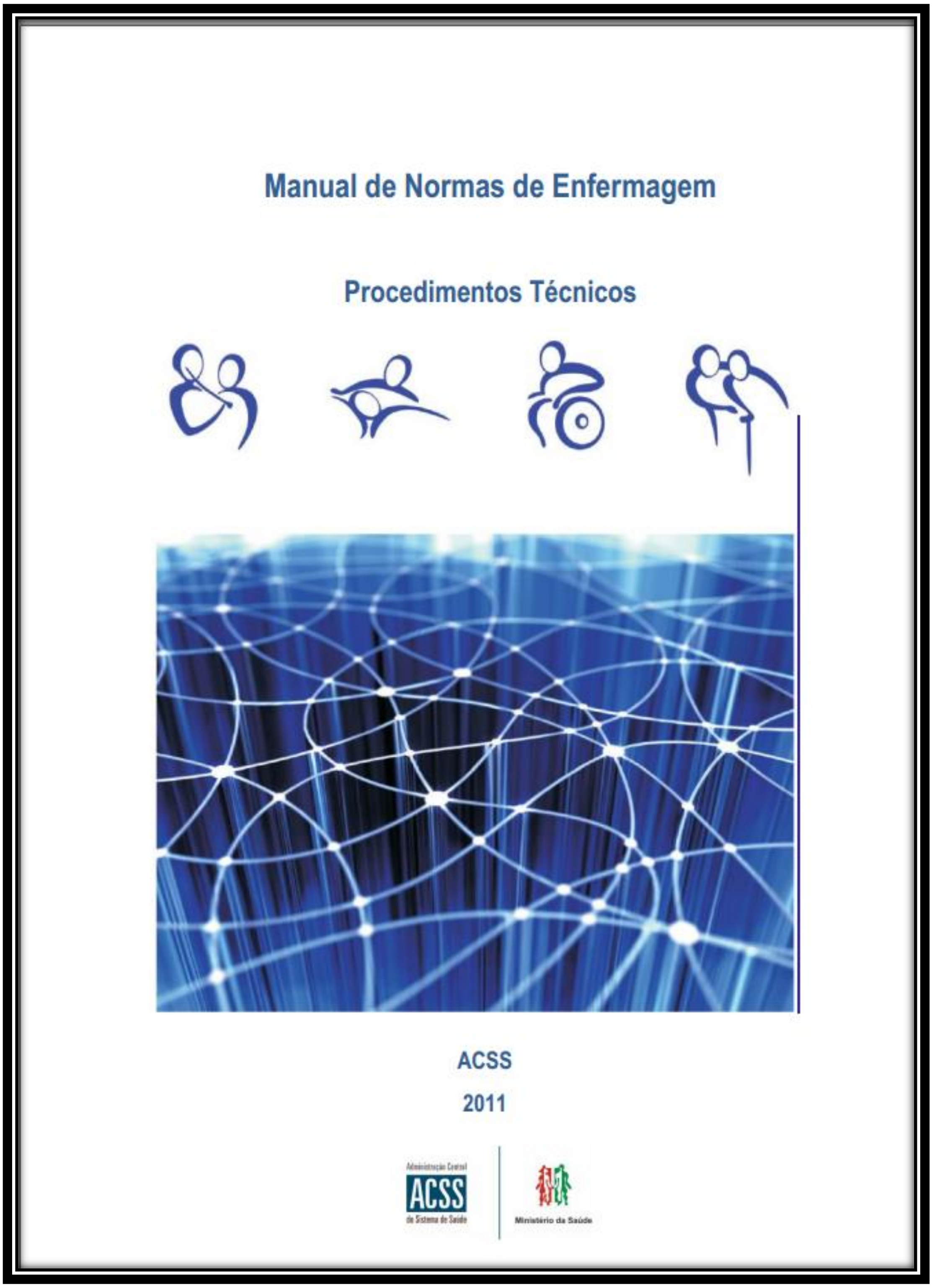
Dimensions and specifications can be decided individually for the application-oriented ball screws and standard nut ball screws. Procedures are as follows. Refer to the selection exercises on page B83.

Table 4.4 is "Combinations of screw shaft diameter and leads for basic type ball screw." Please consult NSK if you require the types that are not listed in the table.



Annex E – Manual de Normas de enfermagem

Procedimentos Técnicos



Annex F – Emerging technologies related to AAL.

Wearable technology

Some advocate that wearable technology is the path that will provide applicable AAL solutions since pieces of this can already be observed with presently available solutions. Solutions like the "BodyGuardian® Remote Monitoring System" (Figure 80) a biometric Sensor that directly adheres to the body and "CarePredict™ Tempo™" (Figure 81) a wrist-worn sensor are already available in today's market. The purpose of these devices is to monitor and analyze activity of daily living and send alerts when unusual patterns begin to emerge.

Figure 80 – BodyGuardian, wearable AAL solution

Figure 81 - CarePredict wearable sensor

Alterations such as anomalies in sleep cycles, changes in posture or walking pace. These are not only advantageous for the caregiver but also to the elderly individual since early warnings of irregularities means they possess more autonomy to address the issue themselves an thus promoting their own autonomy. These devices try to be as un-cumbersome and concealed as conceivable. Nevertheless, they still require to be placed on the body, which can feel unnatural, and nuisance to the wearer thus he can become uncooperative and refuse to wear the device. To resolve this issue, other products possess sensor embedded in the clothing in order to reduce the traces of the sensors and communications device.

However, in both cases, user can simply forget to wear the device, defeating the purpose of such an application. Some defend that these issues can be resolved with the use of long-range biometric sensor, but these solutions still not fully developed do to their complex. The current biggest issue of these applications.[72][73]

Powered Exoskeleton, also known as Exoframe, Exosuit or simply Exoskeleton are another emerging technology that can be considered a wearable technology. They are becoming very relevant wen talking about returning mobility to impaired individuals. The Exoskeleton consist of controllers, actuators (electric motors, hydraulics, etc.), sensors and frame that involves the user's body. It multiplies the energy conveyed to it by perceiving the movement intention of the user's limbs. Therefore, an individual that has not lost complete mobility cam convey some motion to this apparatus to regain some mobility. One of the best examples of this type of application is the HAL: Hybrid Assistive Limb developed and produced by Cyberdyne. It comes in two configurations the "Full Body" that weighs 23 kg and "Lower body" that weighs 15 kg. The "Full Body" type can lift and hold up to 70 kg. Its continuous operating time is roughly 2 hours 40 minutes. [74]

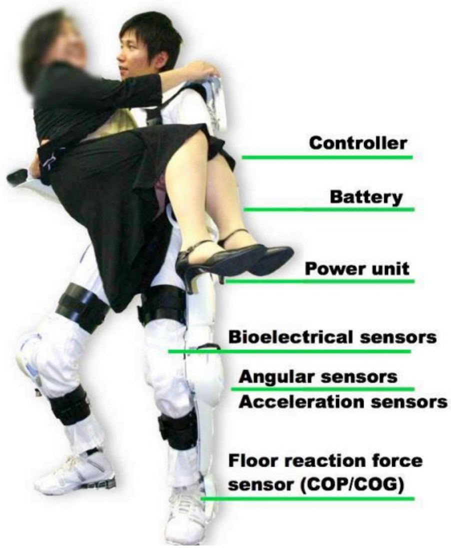


Figure 82 - HAL: Hybrid Assistive Limb, components

In the context of elderly care, what is of note about this device is that both caregiver and BEP's can utilize this device to improve the care experience. For the bedridden individuals ADL's such as standing up or sitting down in a chair, climbing up and down stairs and walking become possible again. For caregivers the physical strength that would be required to perform their duties become lessened so tasks such as moving and repositioning the BEP becomes easier. This an interesting device that emerged from the fields of robotic engineering there are already a few available commercial applications that will be described further ahead.

Advances in the field of robotics

Some robots are already providing invaluable services to their fellow man. The field of robotics is transforming the way that healthcare is being provided in numerus ways. These changes are highly due to recent developments in sensory system, robotic situational awareness analysis, devices to provide motion and electronic components in the field of robotics. These advances are being catapulted by academic research and robotic competition such as the "DARPA Robotics Challenge" and the "Robocup" among many others. The resulting technologies are providing new developments in hardware, software and in man-machine interface. The latter is especially important to AAL since their application are targeted for individual with advance age but reduced IT skills. Therefore, either the UI is simple and easy to use or the control of the robot must be left to the caregivers.

Mobile telepresence robots

One of the features that is contemplated in AAL is the ability provide services by telepresence. Telepresence is a sub area of telerobotics, which means the remote control, or semi control of robotics system. Caregivers and primary care physicians can use telepresence robots to provide nursing (Telenursing) or clinical health care (Telemedicine) remotely, interacting from a distance with the induvial to whom care is being provided. Telepresence can be as simple as an interaction trough a computer and can grow in complexity with the addition of cameras, microphones speaker and other types of sensors. However, telepresence robots take it a step further by adding the ability to move interaction device by remote control. One example of such a device is the "Double telepresence robot" by Double Robotics, seen in Figure 83, it possess also an adjustable height and a self-balancing base.

Figure 83 - Double telepresence robot.

Mobile robot assistants

Some mobile robot assistants also come equipped with telepresence and are used by both caregivers and care physicians to better follow their patients thus improved the care provided. These devices offer other functionalities as well, one of which is the ability to manipulate and/or transport objects in the patient living environment. More and more efforts are being made so the manipulations of objects can be done automatically and provide a truly autonomous device. These devices are becoming kwon as the robot nurses since they are offering invaluable care-oriented support to the elderly. Observing and recording the patient condition and provide assistance with the administer medication of medication are other capabilities that some of these devices offer.

TUG

The TUG, from Aethon, is an autonomously guided robot used currently in healthcare settings such as hospitals and nursing homes. Its primary function is the transportation and delivery of goods such as medication, laboratory samples, food trays and linens. The TUG navigates freely in is through is predetermined routes without constant control from a supervisor. It navigates between delivery points all while avoiding moving and stationary obstacles. This device comes equipped with its own security system so no one besides authorized personnel may access its contents.

Figure 84 - TUG smart autonomous robot[2]

RIBA (Robot for Interactive Body Assistance)

The RIKEN-TRI Collaboration Center for Human-Interactive Robot Research (RTC) presented in 2009 the RIBA (Robot for Interactive Body Assistance) build to aid caregivers in carrying the patients from a bed and to a wheelchair and vice versa. The first generation RIBA could move a person with 61kg but the RIBA II was enhanced to be able to carry in its arms a person with 80 kg. The tactile sensors shown in the Figure 85 enable the robot to sense trough "touch" were force is being applied. With this features the position control of this device is performed using touch so caregivers can position the robot manually without using complex controls. These same sensors also enable the robot to shake hands with users. Is face resembles that of a teddy bear this was done to provide a friendlier visage to the robot so it would be better receive and less frightening to the patients.

[2] Source: http://www.aethon.com/tug/how-it-works/

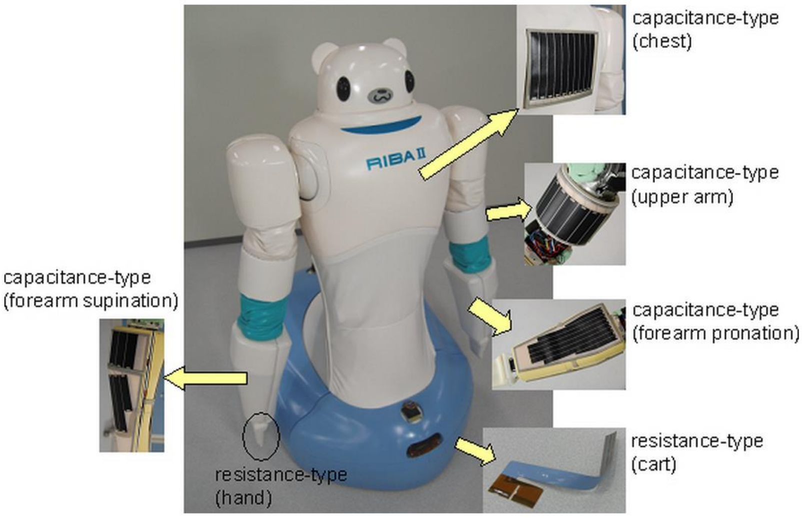


Figure 85 - RIBA-II. Locations of Smart Rubber sensors[3]

Battlefield Extraction-Assist Robot (B.E.A.R)

The Battlefield Extraction-Assist Robot (BEAR) from Vecna Technologies Cambridge Research Laboratory was developed to retrieve soldiers from hazardous terrain. The BEAR can even detect chemical, biological, and explosive agents. This robot requires a remote human operator since the navigation and arm control are semi-automated but development is in a transitioning phase to full autonomous control. Thanks to its heavy-duty hydraulics actuators, the BEAR can lift up to 227 kg making it much more powerful than the RIBA, although these actuator are not suited for the heal care setting.

Figure 86 - Battlefield Extraction-Assist Robot (B.E.A.R)[4]

Care-O-bot

[3] Source: http://www.riken.jp/en/pr/press/2011/20110802_2/

[4] Source: http://www.dtic.mil/dtic/tr/fulltext/u2/a526596.pdf

Development of this device started in 1998 by the Fraunhofer Institute for Manufacturing Engineering and Automation. Completed on January 2015 the Care-O-bot 4 (fourth generation) is the most recent iteration of this device and distinguishes itself from its predecessor by being the first modular commercial developments base platform. The Care-O-bot is interesting because it possess several capabilities seen in other mobile robot assistants combined in one device. Capabilities such as the ability to transport goods, arms and hands to interact with its surrounding, a variety of sensor to perceive its surroundings and many communication and interaction devices. The Care-O-bot can perform speech recognition and gesture recognition enabling him to communicate with its users. The robot can communicate verbally (sound from speakers), trough gestures (nodding, waving arms, shaking hands), visual pointers (pointing with hand or laser pointer) and trough a multi-touch screen. The Care-O-bot comes with a software development kit (SDK) which communities of developers are using further advance the use of robot assistants. All software is open source so the inner workings of the code are better understandable and provide a quicker grasp of the operations. This SDK comes with several variety of service robot components from the fields of navigation, manipulation and perception. [75]

Figure 87 - Care-O-bot[5]

[5] Source: http://www.care-o-bot.de/en/care-o-bot-4/download/images.html

Assistive social robots

Therapeutic robots possess a well-documented positive effect with the individuals that interact with them especially in the case of elderly people and individuals with psychological issues, such as dementia, autism, mood disorders and Alzheimer's. The robot overall appearances and is vital to promote a good reception by the intended user. Humans have a tendency to seek comfort in objects that resemble things with which they are familiar. The therapeutic robots success depends greatly on how they are introduced and employed. Caregivers have a great role since they are the one responsible to formulate the approach and usage of this tool. Some caregivers use these devices only to decrease the levels of stress of their patients. However, if well utilize other benefits appear such as increased in communication activity, both between caregiver and patient but also between patients and other patients. With this communication, other positive aspects emerge such as decline in loneliness and better disposition. [76]

AIBO

Figure 88 - Five generations of the AIBO companion robot[6]

The AIBO companion robot was presented in 1999 and were the first consumer robot of its kind to be available to the public. The AIBO was modeled to resemble a small dog since designer fought hit would be better received. Many studies were conducted where elderly people interaction with this robot as observed and results demonstrate that they were in all well received. The AIBO programing enabled is personality to be shaped by the interaction with its owners and surroundings. The later models possessed touch sensors and facial LEDs, emotional expression to

[6] Source: http://www.sony-aibo.co.uk/

better its interactions with its living environment. Other features included name recording function, voice Recognition and the ability to speak 1,000 words. Sony announced on 2006 that they would be discontinuing all models of the AIBO robots but also said that the knowledge that was gained by the AIBO would find its way on to new products for the healthcare industry.[77]

PARO

The PARO is currently present in several nursing homes in countries such as U.S, E.U. and Japan, where it originates from, as a therapeutic robot for the elderly. The PARO offers the companionship of a small animal without requiring the consequent upkeep and logistical issues such as feeding, bathing and the presence of a live animal in a healthcare setting. As a small animal the PARO responds to petting with sounds and motion and will cry if dropped or ignored. The beneficial therapeutic value of animals interaction with the elderly is well documented and as a property that its creators, AIST a Japanese industrial automation, where set to exploit. This interaction as demonstrated a reduction in the levels of stress of both patients and caregivers and an improvement in the interaction between patient-patient and patient-caregiver. [78]

Figure 89 - PARO seal like therapeutic Robot

ChihiraAico

ChihiraAico, seen in Figure 90, is a communication android developed by Toshiba. Their intent with this human-like female robot was to develop a more human user interface. Since she can understand question and formulate answers providing useful information it is an ideal UI for the entertainment, service and healthcare industry. The realistic visage combined with lifelike facial expressions, powered by 15 actuators, makes this robot ideal for indicating with people. This robot can understand and speak in sign language, since she can talk, and sing makes it the ideal companion for elderly people.

Figure 90 - ChihiraAico is a communication android developed by Toshiba

Annex G – Control software

```
/* Small piece of code that uses a 4X4 keypad to
 * regulate the operations of a table with endstops
 * actuated by a stepper motor.
 *
 * Autor: Bruno Manuel Fernandes da Silva
 * Date:  20-04-2015
 */

#include <Keypad.h>

int  pulPin    = 10;
int  dirPin    = 11;
int  enblPin   = 12;
int  Lendstop  = A0;
int  Rendstop  = A1;

int  count, tot, mid_pos  = 0;

bool change = false;

const byte ROWS = 4; // Four rows
const byte COLS = 4; // Three columns
// Define the Keymap
char keys[ROWS][COLS] = {
  {'1','2','3','A'},
  {'4','5','6','B'},
  {'7','8','9','C'},
  {'*','0','#','D'}
};
// Connect keypad ROW0, ROW1, ROW2 and ROW3 to these Arduino pins.
byte rowPins[ROWS] = { 2, 3, 4, 5};
// Connect keypad COL0, COL1 and COL2 to these Arduino pins.
byte colPins[COLS] = { 6,7,8,9};

// Create the Keypad
Keypad kpd = Keypad( makeKeymap(keys), rowPins, colPins, ROWS, COLS );

void setup()
{
  Serial.begin(9600);
  // Motor

  pinMode(pulPin, OUTPUT);
  pinMode(dirPin, OUTPUT);
  pinMode(enblPin, OUTPUT);

  digitalWrite(pulPin, LOW);
  digitalWrite(enblPin, LOW);
  digitalWrite(dirPin, LOW);

  Serial.println("init");
}

void loop()
{
```

```
//stop everything till the user press a key.
char key = kpd.waitForKey();

//show the key pressed on the computer through the serial port.
if (key) {Serial.println(key);}

  switch (key)
  {
    // Setup
    case '*':
      // roda tudo para a direita

      while(analogRead(Lendstop) >= 100)
      {
        turnLeft();
      }
      count = 0;
      while(analogRead(Rendstop) >= 100)
      {
        turnRight();
      }
      tot = count;
      mid_pos = (int) ((float)count / 2.0);

      while(mid_pos != count)
      {
        turnLeft();
      }
      Serial.print("tolal: ");
      Serial.println(tot);
      Serial.print("midle: ");
      Serial.println(mid_pos);
      key = '0';
      break;

    // Center
    case '5':
      if(count > mid_pos)
      {
        while(count != mid_pos  && analogRead(Lendstop) >= 100)
        {
          turnLeft();
        }
      }
      if(count < mid_pos)
      {
        while(count != mid_pos && analogRead(Rendstop) >= 100)
        {
          turnRight();
        }
      }
      break;


    // Left
    case '4':
      while(count != 0 && analogRead(Lendstop) >= 100)
        {
          turnLeft();
        }
      break;
```

```
      // Right
      case '6':
        while(count != tot && analogRead(Rendstop) >= 100)
          {
            turnRight();
          }
        break;

      // Default Action
      default:
        Serial.println(key);
  }

}
void turnLeft()
{
    Serial.print("Turning Left  count:");
    digitalWrite(pulPin, HIGH);
    digitalWrite(pulPin, LOW);
    digitalWrite(dirPin, LOW);
    count--;
    Serial.println(count);
    delay(1);
}

void turnRight()
{
    Serial.print("Turning Right  count:");
    digitalWrite(pulPin, HIGH);
    digitalWrite(pulPin, LOW);
    digitalWrite(dirPin, HIGH);
    count++;
    Serial.println(count);
    delay(1);
}
```

Annex H – Drum motor driven conveyor design related calculations

In order to know the tension entering the pulley (F_1) and the torque (T) required to move it as necessary to determined physical principal behind the peripheral force witch is the force transmitted through the belt (F_u). First, the sum of the forces influencing the system is made.

$$\sum \vec{F} = F_u + F_r + m\,g \qquad (H\,1)$$

From this the value of the peripheral force (F_u) is obtained.

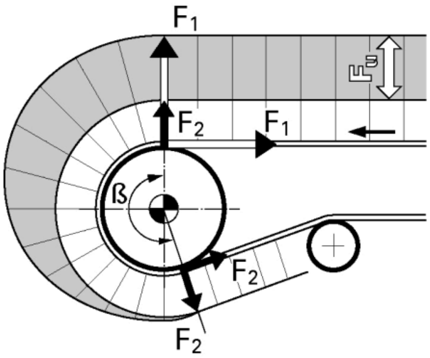


Figure 91 - Representation of the peripheral force (Fu)

The initial tension needs to be sufficient so that the difference between the tensions entering (F_1) and leaving the pulley (F_2) is:

$$F_1 - F_2 = \frac{2T}{d} \qquad (H\,2)$$

Considering that there is no slippage from the belt the following formulas can be combined to ascertain the tension entering the pulley (F_1).

$$F_u = F_1 - F_2 \qquad (H\,3)$$

By determining the torque (T) value, tension (F_1) is now known.

$$\frac{F_1}{F_2} = e^{\mu\beta} \qquad (H\,4)$$

Annex I – Ball screw actuated conveyor design related calculations

Then formula (4.5) provides the operating torque T_a.

$$T_a = \frac{F_a \times l}{2\pi\eta} \tag{I 5}$$

As shown in formula (I 5) the torque T_a is dependent on the axial load F_a, the lead value l, the efficiency η (generally between 90% and 95%). The axial load F_a will very depending on the movement profile. Figure 92 shows the movement profile for the conveyor belt that describes a trapezoidal shape and with the maximum allowed speed is 0,02 m/s.

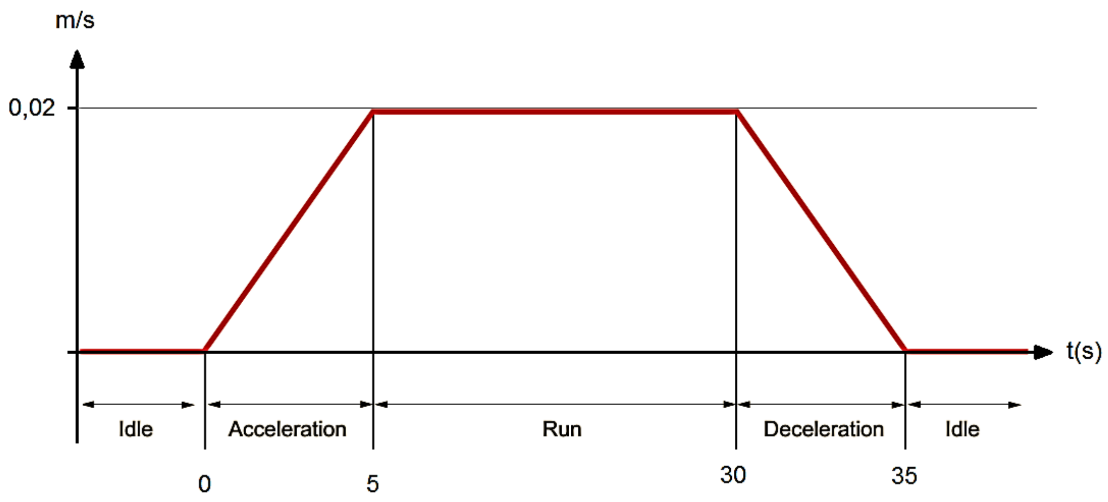


Figure 92 - Movement profile

Acceleration and deceleration at start-up and slow-down:

$$a = \frac{dv}{dt} \tag{I 6}$$

F_a is calculated thusly since the forces in action very within these time intervals. When accelerating from t(0) to t(5):

$$F_a = \mu\, mg + m\, a_1 \tag{I 7}$$

When running at constant speed from t(5) to (30)

$$F_a = \mu\, mg \tag{I 8}$$

When decelerating from t(30) to (35)

$$F_a = -\,\mu\, mg + m\, a_1 \tag{I 9}$$

Equations (I 7), (I 8) and (I 9) represent forward motion, the backward motion values are the negative equivalent of these values. With F_a determined it can be compared with the maximum axial load that this particular ball screw can handle, for this the table with the component reference number is looked up. This particular component can handle an axial load up to 4kN. With these equations, the torque required to drive the ball screw can now be determined but this is not the same as the required torque for the motor to drive the application. To drive the this ball screw the motor must output a torque T_1, where:

$$T_1 = (\,T_a + \,T_{max} + \,T_u) \,\times\, \frac{N_1}{N_2} \tag{I 10}$$

Where T_{max} is the upper limit of the dynamic friction torque of the ball screw and T_u is the friction torque in the support bearings. These are simply the torque values required to overcome the friction values to move the ball screw and bearings. N_1 and N_2 are the number of teeth in gear 1 and 2 respectably.

$$T_2 = T_1 + J \,\times\, \dot{\omega} \tag{I 11}$$

Equation (I 11) provides the drive torque during acceleration T_2. The output to drive the ball screw during acceleration must be equal to the output torque during normal operation T_1 plus the moment of inertia applied to the motor J. This moment of inertia can be obtained by using equation (I 12).

$$J = \,J_M + \,J_{g1} + \left(\frac{N_1}{N_2}\right)^2 \left[J_{g2} + \,J_s + m\left(\frac{1}{2\,\pi}\right)^2\right] \tag{I 12}$$

Where J_M is the moment of inertia of the motor, J_s is the moment of inertia applied to the screw shaft, J_{g1} and J_{g2} are the moment of inertia of the gear 1 and 2 respectably.