COMPARISON OF VARIOUS EXOSKELETON DEVICES TO EXPLORE FOR A NOVEL HYBRID DESIGN

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Abstract - Research into realizing effective lower-limb exoskeletons has become an important necessity in countries where the elderly population is increasing to alarming levels. To maintain independence and good quality of life of elderly persons, lower-limb mobility exoskeletons are expected to play a vital role so that they can continue living in their own homes and carrying out their normal daily activities for as long as possible. This paper explores various devices that are available in the market or at research stage which are meant to bring the change. The aim is to gather the information about different controllers and actuators used in the current devices. This is to be done so an optimal solution in terms of new hybrid design could be found. This will not only reduce the complexity of these devices but will also help to reduce the cost considerably so that general people can have access to them.

Keywords - CVT-Gearbox, Four-bar Mechanism, Lower-limb Exoskeletons, Scotch-yoke Mechanism, Wearable Robots.

I. INTRODUCTION

With the elderly population rising at a rapid rate, it is estimated that the number of people over 65 years old will increase to 98 million around the world by the year 2060 as shown in fig. 1.1. This prediction has led to development of assistive technologies as old age brings several restrictions in terms of movement, which reduces the quality of life (World population ageing, 2015).

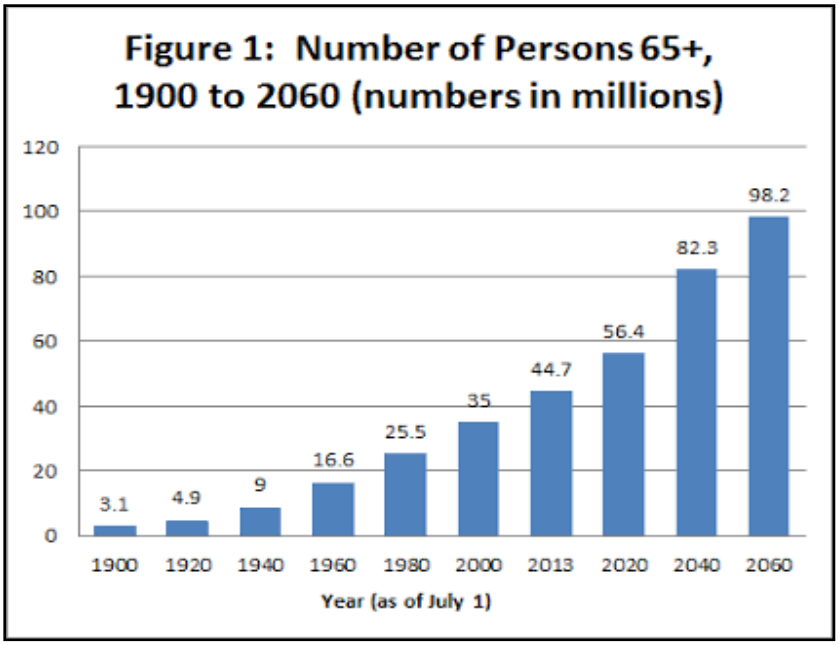


Figure 1: Rise in Elder Population (Source: www.aoa.gov**).**

As people age it leads to various diseases and the need for medical support increases significantly. The given data also reveal that arthritis has affected around 50 million elderly people throughout the world. This has direct effect on their mobility and hence hinders their ability to perform routine activities. The term "Off Legs" is used to describe the situation of elderly people who were able to walk independently but to due to sudden deterioration due to infection or disease of some kind, leads to loss of mobility. A study by Dollar and Herr (2008) listed some of the major problems that elderly people usually face:

a) Not able to stand, sit and walk properly.
b) Always in need of assistance from others in their daily routines.
c) Quality of life is compromised.
d) Financial hardship due to inability to work.
e) Direct effect on human social status.

In last few years, extensive research has been carried out to mitigate the above-mentioned problems of ageing people which could improve their quality of life. Various equipment and technologies have been devised which proved to be assistive in effective rehabilitation of disabled people. This includes wheelchairs, supporting sticks and more. These devices have their own limitations in terms of space, muscle movement and more. Thus, the need for better assistive equipment like exoskeletons (Zoss, Kazerooni and Chu, 2006) is becoming prominent. At the early-stage exoskeleton used to be known as wearable robot.

II. CONTEXTUAL BACKGROUND

The term exoskeleton or wearable robots started gaining momentum in the late 20th century after people started working towards the development of equipment which can enhance the locomotion and physical capabilities of elder and disabled people (Quintero, Farris and Goldfarb, 2012).

The basic structure of an exoskeleton device consists of a driving mechanism (e.g., Motor), control mechanism (e.g., Embedded system), Actuated joints (e.g., hip, knee, ankle-foot orthosis) and optional supporting sticks. The device is useful to give artificial support and momentum to the weaken and disabled joints of patients and thus help to regain rehabilitation. The design and complexity of an exoskeleton device highly depends on the joints of patients that require support and the mechanism required for same. This leads to different categories of exoskeletons which will be discussed in the later section.

From many years, the researchers working on exoskeletons have focused on medical applications and in defence areas as well but recently the interest has started growing in sector to help elder/ageing people in assisting them with their daily routine lives. Aim of this research is to provide mobility independence to elders and disable to improve their quality of life and thus to reduce financial burden of age-care support on government in leading countries like Australia.

Exoskeletons can be classified into different categories based on their area of application. In broader view, based on users, the exoskeletons can be subdivided into two categories:

a) Nonmedical exoskeletons: This category of exoskeletons deals with bulkier and heavy systems. The aim of these devices is to help in multiplying the force applied by soldiers to a certain level. It is also required to aid the soldiers in carrying heavy weights over long distances.
b) Medical exoskeletons: This category of exoskeletons incorporates more complex control systems than the former ones. The aim is to help elderly people to restore their gait movements and achieve mobility independence. This category generally focuses on designing exoskeletons which are compact as users wearing this cannot handle the excessive weight and thus needs costly mechanisms. This study will be concentrated mainly on medical exoskeletons.

There are many other exoskeletons available which makes use of different technologies and have their own merits and demerits. For this research important factors of consideration are the types of actuators and controllers being used in some of the leading devices. This will help to understand the effects of same on weight and cost of these devices. The following table summarizes different types of devices with a focus on the stated factors in attempt to understand the better picture.

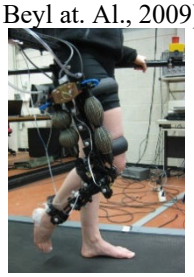
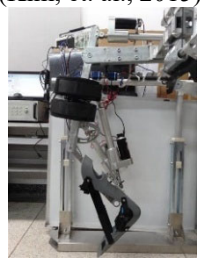
On further in-depth understanding of the given categories of exoskeletons, it is observed that power, control mechanism, and cost are the key factors which need to be addressed for designing a novel hybrid mechanism. These factors are important for elderly people to decrease their dependence on others for mobility and at same time reducing the cost of elderly care.

Power of an exoskeleton device is one of most important aspects as it directly relates to payload capacity and working efficiency. It can be defined as its capacity to lift the load as compared to its own weight. In the case of elderly patients where natural limb movement is significantly less, power of an exoskeleton device becomes the most important factor. If the exoskeleton is designed in a way to provide sufficient power, for instance, to the knee joint, then only that aim is achieved. When the exoskeleton is designed for army purposes where a soldier already has sufficient limb movements, the role of the device is to augment the same. This can be achieved using hydraulic and pneumatic actuators. In the case of elderly people, controlled power is the aim otherwise it could result in hazard situations. Therefore, when designing an exoskeleton for elderly patients, power is an important consideration, and the choice of actuators should be made accordingly. Moreover, there is very little or no feedback from users' movements in the case of medical exoskeletons; hence the power output becomes an important consideration while design phase and limiting values have to be applied. This means that when the geometric modelling of the hybrid mechanism for exoskeleton is carried out then power output is an important factor to be considered.

Control Mechanism is another important key feature that needs to be focused on while designing an exoskeleton, especially for elderly people to restore

their gait movements. On comparison with other class of exoskeletons, like defense ones, the devices built for elderly people and patients suffering from paralysis and other diseases which affects their mobility require more precisely controlled systems. For this more complex system? actuators and controllers are used which include DC (Direct Current) motors, EMG (Electromyography) controllers, high end sensors, and more. This results in more efficient and safe systems but at the same time, they are relatively costly and complex which makes their use impractical by general users. Therefore, these devices are installed in medical facilities and require experts to operate them to help patients to regain mobility and in gait assistance.

Exoskeleton	Actuator type	Controller type	DOF	Weight (kgs)	Cost
Ekso (Ekso Bionics) 	Electric motor, spring	Gesture based HMI	6	20	100,000 USD
ReWalk (Goffer, 2014) 	DC motor, spring	Pre-programmed motion control	6	23.3	85,000 USD
Indego (Indego.com) 	DC brushless motor	PMC	6	12	140,000 USD
Rex (Viteckova et. Al., 2013) 	Electric motor	joystick	10	38	150,000 USD
LOPES (Veneman et. Al., 2007) 	Series elastic actuator and Bowden cables	Impedance	8	Not available	NA (Research stage)

KNEXO (Beyl at. Al., 2009) 	Pleated pneumatic artificial muscles	Physical human-robot interaction	1	4.4 (each leg)	NA
Nurse power assist suit(Yamamoto et. al., 2001) 	Pneumatic rotary actuators	P controller pressure	6	Not available	21000 (prototype)
Honda Leg-Walk assist (Kusuda, 2009) 	Brushless DC motors	Battery controlled	2	6.5	On lease in Japan
BLEEX (Kazerooni, 2006) 	Hydraulic linear actuator	P controller, sensitivity amplification controller, joint angle.	14	43	Research stage
HLEER (Kim, et. al., 2015) 	Hydraulic double cylinder	PD controller force and angle	12	45	Research stage

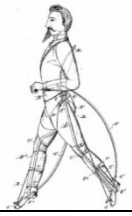
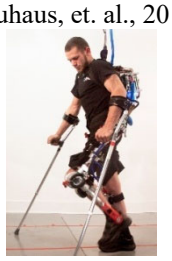
Hardiman (Mosher , 1971) 	Hydraulic actuators	Force interaction controllers	28	680	Never fabricated for market
Yagn's running aid (Herr, 2009) 	Springs, gas bags and links	Human interaction	1	NA	Never built
XI Mina Exoskeleton (Neuhaus, et. al., 2011) 	DC brushless motor, harmonic drive gear reduction	PD control torque	4	Not mentioned	NA

Table 1: Comparison of different Exoskeletons

Cost is a third key factor while designing these kinds of devices. The aim of making elderly people independent in terms of locomotion requires the cost factor of exoskeletons to be realized so that they can be affordable. To reduce this problem of high-cost devices, the aim is to search for alternative components which can help to achieve the desired control and robustness but at same time be more affordable and specific to this area of need. For this data, different devices like CVTs, scotch yoke mechanisms and others will be analysed to construct a novel design by combining the most suitable mechanical devices together, so that hybrid mechanism could be built to serve as a lower limb affordable exoskeleton.

III. CONCLUSION

The problem of varying speed/torque ratios at individual motor level is seen in all exoskeletons which use gearhead and harmonic drives with the motor. Harmonic drives are used for large reduction ratios to provide the high required torques; these devices are quite efficient but are costly. Moreover, by using gearheads and harmonic drives, the overall efficiency of the drive is reduced, and the metabolic cost also increases (Gregorczyk, et al., 2010). To address these problems, alternative viable solutions are needed which can provide the required speed/torque characteristic at each joint. This can be done by coupling the motor with a mechanism which does this without disturbing the constant speed of the motor. The concept of Continuous Variable Transmission (CVT) used in automotive applications has been suggested for this by Singla et al. (Singla, Rupal, Virk, 2016) so that motor torques can be varied as needed for performing daily living tasks and the feasibility with conventional mechanisms checked.

CVT mechanisms have not yet been used in assistive exoskeletons although they have been extensively used in automotive applications. It is felt with sufficient miniaturization and optimization for wearable exoskeleton applications, CVTs could improve the effectiveness of assistance provided to wearers and thus advance the emerging technology to meet the global need of the ageing society. The aim here is to explore the potential CVTs in assistive exoskeletons.

Further, conventional mechanisms such as scotch yokes (Clausen, 1945), and four-bar mechanism (Pons, et al., 2007) are investigated for their feasibility to use in wearable exoskeletons.

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