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Low-cost active knee orthoses – a systematic evaluation

Assisted stair climbing and sit-to-stand

Abstract: The aging of humans induces muscle weakness. Muscle weakness results the inability to climb stairs or stand up from a chair and thus, is one of the first steps towards elderly having a less autonomous and self-sufficient life. Therefore, an accessible active knee orthosis, which especially supports these movements would be of great assistance. Recent research projects have focused on feasibility, perfection of motion control and imitation of human movement. For active knee orthoses to be accessible it must be affordable. Hence, this paper systematically evaluates the current research projects around active knee orthosis and discuss the possibilities of implementing a low-cost active knee orthosis.

Keywords: active knee orthoses, low cost, stair climbing, sit-to-stand

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1 Introduction

In Germany, the average age and life expectancy is increasing [1]. In addition, many elderly people become restricted in their mobility [2]. In particular, they are unable get up from a chair [2] or to climb stairs. As a result, the crucial loss in their autonomy negatively effects on physical condition and social life [1]. Active knee orthosis, which assists elderly mobility, particularly stair climbing and/or sit-to-stand movements (STS) would allow elderly people to be self-sufficient for a longer period of time. However, the great cost associated with such a device is a large barrier to accessibility, especially in emerging and industrial nations with demographic change. For example, health insurance funds make their reimbursement conditional on cost-benefit-

ratio [3].

This paper gives an overview of active orthoses, found in literature which assists people to climb stairs or get up from a chair, focusing particularly on the relative importance of cost in each device. In addition, the main contributors to cost in active knee orthoses are discussed. Looking at a list of cost factors is worthwhile, as it presents areas of potential reductions in active knee orthotics.

2 Methods

The current literature was reviewed in relation to active knee orthosis which provided both assistance in climbing stairs and/or standing up from a chair. Each of the relevant published active knee orthoses were then assessed in regard to the importance of cost and methods of reduction. Publications were selected as follows:

1. Literature search of all active knee orthoses
2. Selecting the active knee orthoses which belonged to a current research project and/or were commercially accessible
3. Selecting the active knee orthoses which provided assistive movement to elderly or those with muscle weaknesses, and assisted in stair climbing and/or getting up from a chair.

All of the active knee orthosis publications were primarily compared in relation to the assistive movement provided. Secondly, each publication was compared in terms of cost factors. Overall, this comparison allows for potential reductions in cost to be easily observed.

3 Results

3.1 Active knee orthoses

Since the late 1960s many people have researched and published in the field of lower extremity exoskeletons and active orthoses [4]. However, many are no longer currently

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being researched (Step 1). There are now however, more than 50 active knee orthoses known to be commercially available and/or part of a current research project (Step 2) [5]. Note, the majority of the active knee orthoses found in literature are still connected to research projects and are trying to improve feasibility, which implies an increase in high-level technology being used [6].

Table 1: Active knee orthoses found in literature, which address elderly (E) and people with muscle weakness (MW) and assist Stairclimbing (STC) and/or Sit-to-Stand (STS) (with or without Walking (W)); (CA = Commercially available, RP = Research Project)

Manufacturer/ University	Country	Stage	Target Group	Assisted Movement	Source
B-TEMIA Inc	CAN	CA	MW	W, STC	[7]
Istituto Italiano di Tecnologia	ITA	RP	MW	STS	[8]
Meiji University Graduate School	JAP	RP	MW	W, STC	[9]
National Tsing Hua University	TWN	RP	MW,E	W, STC	[10]
Peking University	CHN	RP		W, STC	[11]
Technische Universität Darmstadt	GER	RP	MW,E	W, STS, STC	[12]
The University of Tokyo	JAP	RP	MW, E	W, STS	[13]
Université Paris-Est Créteil	FRA	RP	MW	STS	[14]
University of Alabama	USA	RP	MW, E, R	W, STS, STC	[15]
University of Canterbury	NZL	RP	MW	STC	[16]
Vrije Universiteit Brussel	BEL	RP	MW	STS, W	[6]

The focus of this work is reviewing active knee orthoses which assist elderly in stair climbing and getting up from a chair, not solely assisting in normal walking or particularly physically exhausting activities. Thus, the target groups identified for this study are elderly (E) and people with muscle weakness (MW), not the military. In addition, the assistive movements provided by the active knee orthoses

were identified as 1 of 3 types: stair climbing (STC), sit-to-stand (STS), and walking (W). Each publication was assessed in terms of these two criteria, “target group” and “assisted movement” (Step 3)

Table 1 shows the remaining 11 active knee orthosis projects which provided elderly and/or muscle weakened people assisted movement in stair climbing or getting up from a chair.

No differentiation was made between active orthoses that applied assistive movement to the knee and other parts of the leg (KA, KAFO, HKAFO).

Most of considered projects apply pneumatic artificial muscles [9,10,15,16]. The focus areas of the presented research projects could be divided into five main research fields. The biggest field being the control of the actuators including sensors [8,10,12,14,15]. Another significant research field is the detection of the user’s intended motion [8,16]. Some research projects focus on the man-machine-interaction providing the actuation itself [6,9,10,12,13]. User’s comfort, safety or prototype’s weight are other important emphases [6,11,12]. It is being attempted to understand and imitate the human knee movement as accurately as possible [11].

3.2 Low-Cost active orthoses

In other research areas, which have created alternative (not active knee orthosis) assistive mobility devices for elderly standing up from a chair, researchers have focused on cost reductions [2]. However, the requirement of the active orthoses being “low-cost” was found rarely in the literature reviewed. Only Brackx et al. presented a “low-cost, low-weight, compliant actuator unit that can be easily mounted on commercially available orthoses” [6]. Cost appeared to be of relatively little or no importance in the other reviewed active knee orthoses.

Beyond what was reviewed in Table 1, some potential cost reductions in active knee orthoses are found. Font-Llagunes et al. focused on a low-cost design of their robotic rehabilitation orthosis. They designed their orthosis “by adding a motor at the knee [to a passive device], that can move or lock the joint, and an inertial measurement unit (IMU) at the shank to detect gait events” [17]. Saggio et al. described a low-cost sensor-based measurement system for the knee flexion angle [18]. The feasibility of low-cost orthotics is becoming increasingly possible, especially in custom made passive orthotics, due to the developments and resulting possibilities with 3D-scanning and -printing [19].

4 Discussion

Brackx et al. criticise in relation to active knee orthoses that “developments in research around the world are often complex, not modular and expensive” [6]. This was found to be very noticeable, with only Brackx et al. being identified in this paper. Therefore, highlighting the lack of research into low-cost feasible active knee orthoses.

The costs associated with active knee orthosis depend on many different parts of the device. They can be divided into three groups: before, during and after the elderly live with the supporting device.

The researchers and developers can influence the costs while designing their active knee orthoses. Some of the published active knee orthoses are made of a standard passive part fitted with an active part [6,12,15,16]. The used materials significantly influence the build and maintenance costs of the complete orthosis. As active knee orthosis commonly has passive elements, the materials used in such a device will likely be present. In commercially available passive knee orthoses, mostly metal, leather [20] and foam linings are used [21]. If the passive knee orthoses are custom-made to fulfil “cosmetic” [21] claims, materials such as carbon fibre and thermoplastics are commonly used. In addition, in active knee orthosis devices, materials such as carbon fibre [16], metal [15] and plastics [10] (for covering the major components or moulding to the user) are also seen to be used. Construction also strongly impacts the costs. In passive KAFOs the joint elements are the main cost drivers [21]. However, from the review of publications of active knee orthosis it appears that the active parts have the biggest influence on the costs. This is likely due to the added complexity involved with active knee orthosis. The active part of any orthotic device usually consists of many parts, e.g. motor, gearbox, sensor technology and control. Counting the number of implemented components and comparing the overall amount between publications could be a first, rough approximation of the costs associated with published active knee orthoses. However, the mentioning of the implemented components considerably varies in the selected publications. Thus making it very difficult to make an informed choice of the costs. However, in the majority of publications the actuation and control systems contain the most components. For example, in Pott et al. [12] four of the eight mentioned parts (50%) are related to the actuation system, two parts are related to the control system, and the other two are components are related to the passive part of the orthosis. Every part likely increases the orthotic devices expensive. Therefore, simple design of few parts should be favoured for low-cost knee orthotics.

When a person gets an active knee orthosis instruction is required [7]. As a result, complex operation associated with increased staffing is another cost factor [21]. Therefore, simple construction with easy handling and operation will also help reduce costs.

During the utilisation period the amount of services and repairs contribute to the over-all costs of an active knee orthosis. For this purpose, again a simple construction would be favoured.

In regard to the disposal and recycling it is also advantageous to design the active knee orthosis as simple as possible.

The mentioned points are relevant reasons why an accessible active knee orthosis should not be “complex, [...] and expensive” [6] but simple and made of as few parts as possible.

As mentioned in 3.1 many research projects focus on the control and sensors. That is why research projects in low-cost measurement systems (e.g. [18]) could be advantageous for a low-cost solution of active knee orthoses.

Therefore, to make active knee orthoses simple and comfortable, a good compromise may be to combine a low-cost personalised passive knee orthoses based on 3D-Scanning and -Printing with low-cost actuators and less sensors as possible.

The actuator parts of active knee orthoses contribute to much of the costs associated with active knee orthosis. Therefore, research projects into alternative, new and low-cost actuator systems, like shape-memory (SMA) or twisted-string actuators (TSA) [5], could be very useful. Actuation systems which combine the actuation role with some aspects of control, like SMA, could be a perfect option to reduce implemented components, and thus the overall costs.

5 Conclusion

Most research projects concentrate on the perfection of motion control, imitation of natural movement and other factors such as weight and comfort. These are all important points to support elderly and improve their acceptance, however, providing a low-cost, and thus highly accessible device is also equally important. This crucial point rarely considered in the current research reviewed. Affordability of active supporting devices is essential to making these devices accessible to all. Only an accessible active knee orthosis enables people to increase their quality of life.

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