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LOPES: a lower extremity powered exoskeleton

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I. INTRODUCTION

Due to aging of the population, growing numbers of people are affected by impairments of their motor system, caused by disorders like stroke. Treatment of stroke patients is very intensive in the amount of training per patient per day. The treatment duration per patient combined with the total number of people suffering from a stroke makes rehabilitation therapy extremely costly. This makes devices that could reduce the costs of therapy attractive to rehabilitation centres. Currently there are robotic rehabilitation devices under development [1-3] for both the upper and lower extremities. Our group focuses mainly on the recovery of gait after stroke. The LOPES robot is designed for use in training on a treadmill to accommodate for limited space of rehabilitation centres and easy access for the therapist to the patient. As a 'robotic therapist' it is meant to make rehabilitation more effective for patients and less demanding for therapists [1], [2], [3]. This claim is based on the assumptions that:

- intensive training improves both neuromuscular function and all day living functionality [4].

- a robot could be well able to train a patient at least as effective manual training [7], [8],

-a well reproducible and quantifiable training program, as is feasible in robot assisted training, would help to obtain clinical evidence and might improve training quality [8].

We claim that passive walking can not be considered task specific training, as the patient is not carrying out the task himself. There are indications that task specific training leads to better results in the relearning of motor functions [5], [9]. Our exoskeleton is designed to offer a task specific training to patients by defining different tasks within the gait cycle and supporting those tasks separately depending on the patients needs. e.g. If a patient is unable to effect sufficient foot lift the robot will support the foot lift but will not be active in the rest of the gait cycle. This will hopefully lead to more active walking from the patient's side and thus a more task specific training. For the exoskeleton this means that it ideally would have a zero mechanical impedance when not supporting and a high impedance when fully supporting the robot. In order to be able to offer this range of support we have chosen for series elastic actuation driven by a Bowden cable [10] and a compliant control scheme based on virtual model control [6].

II. VMC

For the control system this means that it should be able to take over all functions and still be able to reduce the perceived impedance to the patient to a level that is close to zero. We propose Virtual Model Control (VMC). This method has been implemented in the control of several walking 2D robots [6] and 3D robot models. Virtual model control is a motion control framework that uses simulations of virtual components to generate desired joint torques. These joint torques create the same effect that the virtual components would have created, had they existed, thereby creating the illusion that the simulated components are connected to the real robot. Using virtual components such as inertias, springs and dampers it is possible to simulate any interaction that a therapist would usually have with a patient. For example in order to make sure the patient's foot does not hit the floor while walking. A non linear virtual spring damper could be assigned to simulate the behavior of a roller-skate keeping at a certain height above the floor. We have defined several virtual models that should span the entire gait cycle (fig II)

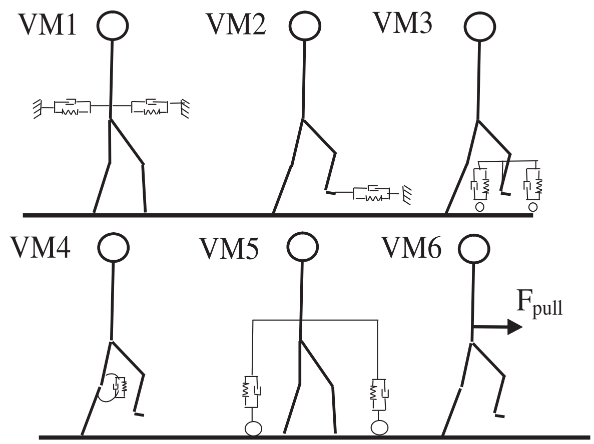

Fig. 1. Examples of Virtual Models(VM) to support gait. VM 1 supports the balance of the patient. VM2 assist the patient in the placement of the foot in the sagittal and frontal plane, which is important for dynamic balance and the speed of walking. VM3 enforces sufficient foot clearance using a virtual granny walker connected at the ankle. VM4 helps to stabilize the knee. VM5 is a virtual granny walker (partial) supporting the patient's weight. VM6 increases the patient's push off.

III. CONSTRUCTION

We have chosen for a exoskeleton fig III structure as an this type of construction can physically be given the same movement constraints as the human body leading to a higher degree of safety.

A. Degrees of freedom

In order to support all gait functions (fig 3) the robot needs the following degrees of freedom (definitions of the used DOF's are given in (fig 4):

- *Hip Ab/Adduction* : sideways balance training.
- *Hip flexion*: the forward progression and balance

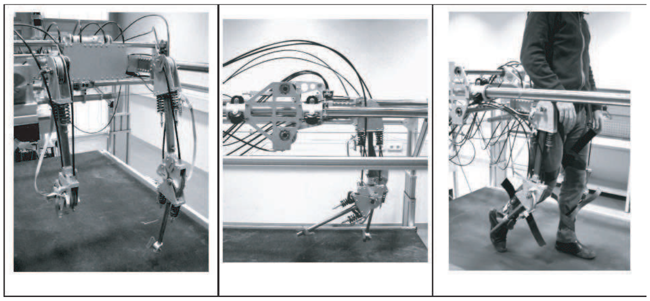

Fig. 2. A photographic impression of the resulting total construction of the exoskeleton

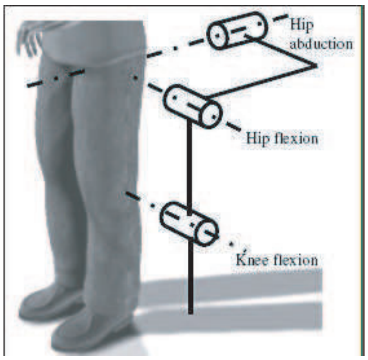

Fig. 3. The degrees of freedom per leg

- *Knee flexion*: foot clearance and knee stability
- *Horizontal pelvis translation*: sideways balance
- *Vertical pelvis translation*: allow natural accelerations of the COM.

Very few robots on the market today allow abduction of the leg. We have chosen to implement this degree of freedom because it offers the possibility to train sideways balance. Something which is crucial for normal walking.

B. Actuation

If the patient should be able to walk unimpaired by the robot for part of the gait cycle while maybe fully supported in another phase the actuation should be:

- back driveable
- light weight
- a high force bandwidth source

To this end we have developed and tested a bowden cable driven series elastic actuator [10] (fig 3). We chose to Bowden cables to separate the motor from the frame and thus reducing the moving mass on the exoskeleton. The springs are used as low cost force sensors and can be used to cancel out the non-linear effects of the bowden cables. The motors can offer moments of up to 75 Nm around each hip and knee joint and 50 Nm around the abduction joints. Horizontal movement in the pelvis is actuated by a series elastic actuator in the sideways direction (maximum force 200N) and a linear direct drive in the forward direction (maximum force 200N)

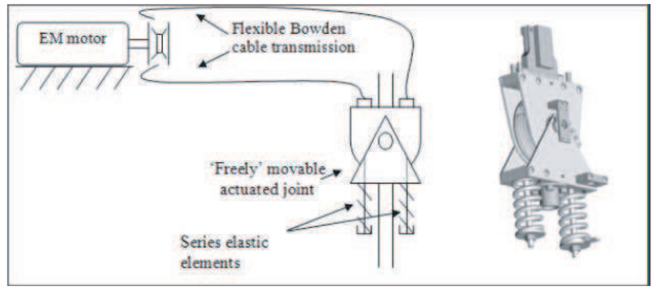

Fig. 4. A schematic representation of the bowden cable driven series elastic actuator

IV. Preliminary results

At the moment we have executed free motion trials on healthy subjects. Preliminary results indicate that walking in LOPES does not significantly change muscle activation (EMG) measurements during walking. Although the robot was initially designed for gait rehabilitation the system bandwidth allows for a wide variety of gait related research as it is possible to walk at normal speed and to perturb gait during walking. Also as all interaction moments are measures in combination with the joint angles this device can be used as a diagnostic device. The bandwidth is high enough to allow a person to run and any other type of forward progression.

V. Future Work

Future work In the near future we will implement support for all gait functions and will evaluate using healthy test subjects. Clinical trials should start in the first half of 2007.

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