Design of a walking-aid and sit to stand transfer assisting device for elderly people

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Abstract

This paper describes the preliminary design of a light, high stability, robotic system for elderly assistance. The mechanisms used for such assisting devices must exhibit complex mechanical functions that may change during the use. The design was built up thinking about the constraints of a chosen pathology. Taking these constraints into account, the design of a robotic walker is presented which provide support during sit to stand transfer and during the walk.

1 Introduction

Instability and falling are among the most serious problems associated with aging. Age-related changes in the neural, sensory and musculoskeletal systems can lead to balance impairments that have a tremendous impact on the ability to move safely, and the consequences of instability and falling, in terms of health care costs and quality of life, are significant. It has been stated that 28-35 % of community dwelling people over the age of 65 years and 42-49 % in people over the age of 75 years will experience at least one fall.

A number of studies have explored the role of visual, vestibular and somatosensory systems in the control of upright posture ([1], [2], [3]). It is well established that some features of postural control change during the advancing years of life so that the stability of posture can be a problem in the Elderly ([4]). However, neural mechanisms of postural stability that decline with age and make older adults more prone to falling have not been identified specifically. Bone fractures or other bodily injuries, and more generally functional decline result from elderly people loss of balance. This restricts their movements and social activities, causing depressed moods and decreased enjoyment of life.

Robotics technologies have been investigated in the recent past to prevent falls by a postural control of patients and to promote safe mobility ([5], [6], [7]). In this paper, we describe the design process of a technical aid for elderly people (see Figure 1). This system is intended to solve two main problems associated with aging: (1) sit to stand transfer, (2) walking stability.

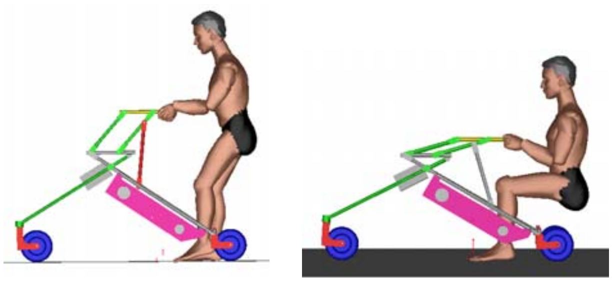

Figure 1. A walking-aid and sit to stand transfer for elderly people

Based on an analysis of the most common walking trouble associated with aging (presented in section 2), we first design the overall kinematic of our walking aid. Then we present the experimental setup used to simultaneously record the hand position and the interaction forces during aided sit to stand transfer. These data are then used to find the optimal values of the link lengths as well as the minimal required torques for each actuator.

2 Disturbances induced by some particular pathologies

Walking troubles of elderly people are a permanent preoccupation in rehabilitation. An important corollary is the fall with its physical, functional and psychological consequences. Injuries with bone fractures and fear of fall (post-fall syndrome) are the main pathologies appearing after a fall.

2.1 Surgery of the lower limb

Rehabilitation exercises after surgery of lower limb needs to be done as soon as possible. Thus, nurse staff need to spend a lot of energy and time to encourage and to incite patients to stand up and to walk. The rehabilitation is actually made with some technical aids like parallel bar, hoist or zimmer, which are very rudimentary devices. Active devices for postural compensation can then free nurses for other tasks, and help elderly people to do rehabilitation exercises with various difficulties. The postural compensation needed here is to help patients to stand up and to walk by their own self.

2.2 Post-fall syndrome

The syndrome of «post-fall» can affect elderly people who have fallen. This syndrome leads to a regression of the locomotion system in two ways: psychological trouble and disturbance of gaits and posture. The retropulsion, which is one of the psychological consequences of the fall, leads to a disturbance of posture: patient has a tendency to fall behind without compensation reactions, which could restore balance. The elderly must so be assisted in the sit to stand transfer and in walking with a zimmer. As a matter of fact, sit to stand transfer needs an antepulsion posture such that configuration of the body can provide propulsion in the direction of the motion. Patient sited-down with retropulsion cannot use properly his body to get into an antepulsion position, as illustrated in Figure 2. In this case stand-up is very difficult.

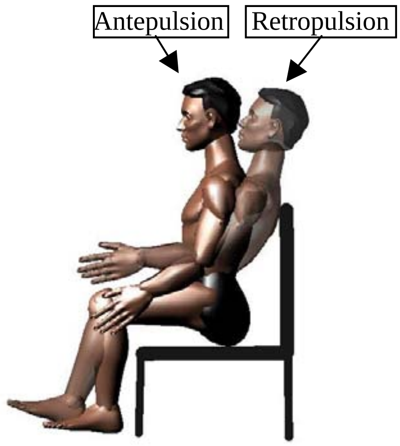

Figure 2. Antepulsion and Retropulsion postures

In the case of retropulsion, the walking posture is also modified into an abnormal position of the body. The torso is lined backward with shuffling gait. Then, projection of the gravity centre of the body is not between the two feet. The configuration does not guarantee the stability of the elderly and increases the risk of fall during the walk.

As for rehabilitation exercises after surgery of lower limb, the postural compensation needed here must help patients to stand up and to walk by their own self.

In the following sections, we present the design of a robotic device, which will help elderly in the two following physiological functions:

- Sit to stand transfer
- Stability during walking

3 System design

The design of a light system exhibiting high stability is obtained with the methodology presented in Figure 3.

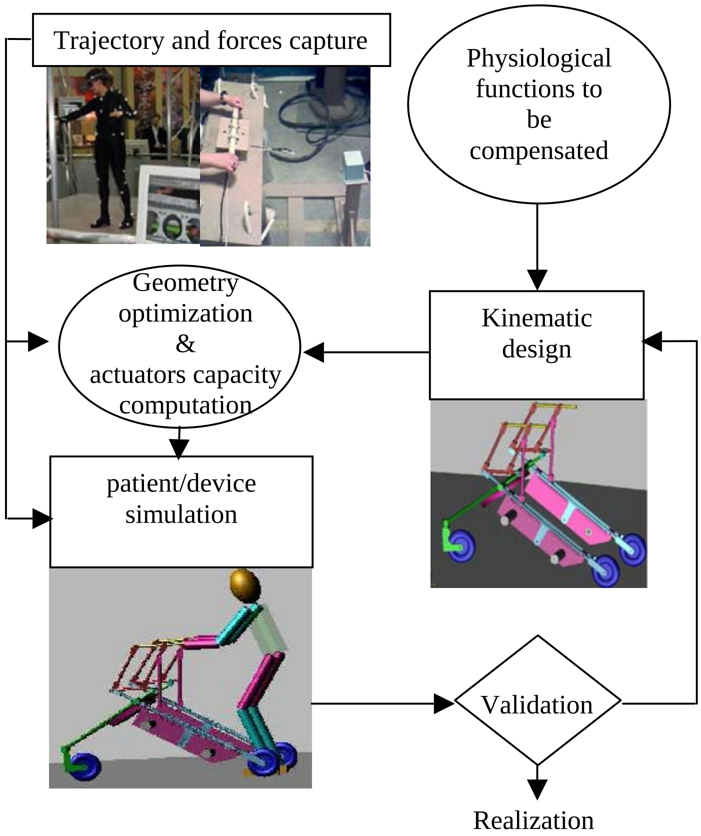

Figure 3. Design procedure

The method employed for the preliminary design of such systems is based on three parts:

1. The overall **kinematic design** is done from the analysis of the complex mechanical functions compensating the physiological function injured.
2. The **Geometrical parameters** optimization and the actuators capacity definition are performed using experimental measurements made on patients.
3. The **Dynamical simulation** of the couple elderly/system is used for an evaluation of the mechanical design

3.1 Kinematic design

The robotic system is basically made of a two degrees of freedom mechanism mounted on an active mobile plateform.
The robotic system must first ensure the stability of patients during the walk.
As human walking may be seen as an inverse spatial pendulum ([3]), we must design an active mobile platform, which can move in any direction to balance elderly. This may be done using a holonomic wheeled-platform with two driving wheels and a front mounted caster wheel. A stable walking is obtained if the projection of the center of gravity of the couple wheeled-platform/patient is inside the polygon support defined by the three ground/wheels contact points. This condition can be achieved by choosing a relative position of the handles and the back wheel such that the back wheels positions are always behind the feet. This constraint will be included in the optimization process described in the next section.

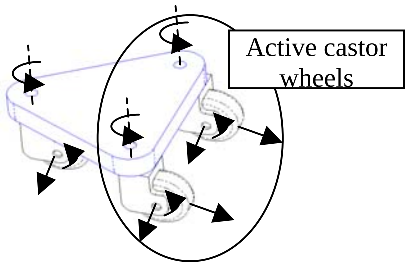

Figure 4. Holonomic wheeled-platform

The handles are independent in order to balance elderly exhibiting a lack of symmetry with respect to the sagittal plane when walking.

The device must also assist elderly in the sit to stand transfer.
To be lifted softly, the handles must first pull slowly the patient to an antepulsion configuration. Then, the handles go from this down position to the up position, which is the position used for walking. Obviously, the handles must remain horizontal during the whole transition. This is obtained using two parallel mechanisms combined in a serial way (passive four bars linkage and “balancier d’Evans”), as illustrated in Figure 5.

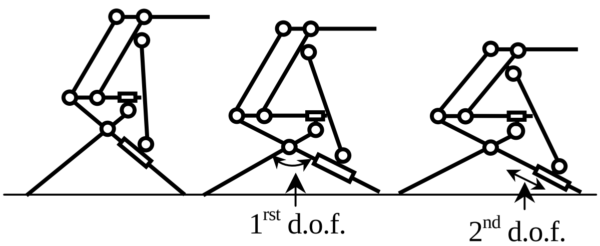

Figure 5. Handle mechanism

The whole mechanism, illustrated in Figure 6, needs a total of 8 actuated degrees of freedom:

- 6 actuators for the driving and steering axis of the 3 wheels. When the front wheel is locked, the motion of the two back wheels leads to a variable wheelbase that is the 1st dof of the handle mechanism defined in Figure 5.
- 2 linear actuators for the motion of the two independent handles.

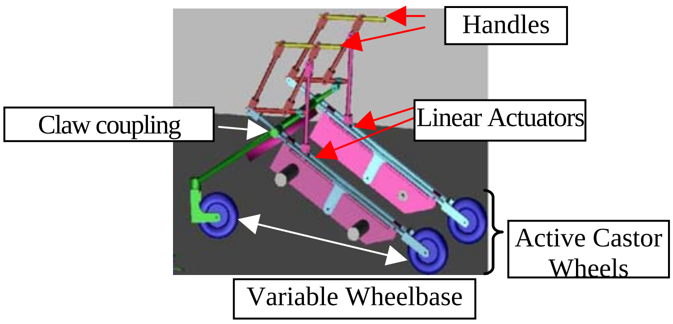

Figure 6. Kinematic of the walking aid.

The next step in our design procedure is to find the dimensions of the links and the actuators capacity. These values are closely related to the support force of the patient. Maximum support force values have been reported by researchers of the PAMM project [8] and of the Care-O-Bot project [9] but for robotized walking-aid. To have a valuable insight into the trajectory and the handling forces along the trajectory, preliminary experiments with the actual users through field tests have been conducted. These experiments are described in the next section.

3.2 Motions and forces measurements

The two main informations required for the design are the up (patient standing) and down (patient seated) positions of the handles and the maximum forces needed to balance the elderly during the sit to stand transfer. To get these informations, we use a 6 axis force/torque sensor to measure the handling forces and two 6 axis position/orientation sensors (mini-bird) to measure the displacement of the hands and of the torso of the patient.

The test platform is composed of two handles for the two caregivers and, in the center of the platform, a handle for the patient mounted on the force/torque sensor. One of the position/orientation sensor is mounted on the patient's handle and the other one on his torso. These sensors are connected to a computer (Real Time Linux) used to simultaneously and in real time record the forces and trajectory during a sit to stand transfer.

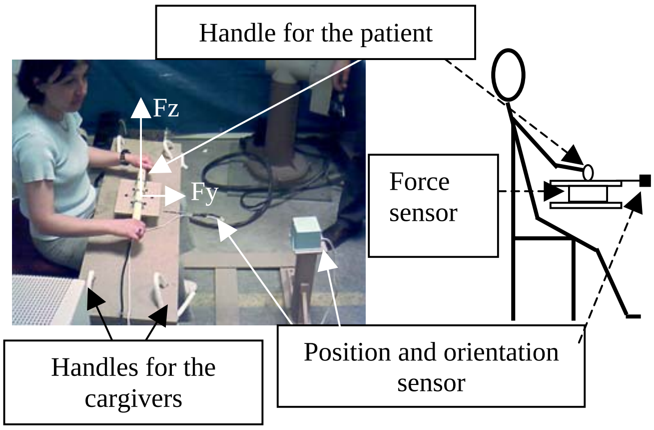

Figure 7. Experimental test-bed

Experiments have been conducted on a set of elderly patients in Charles-Foix Hospital. For these experiments, the patient is seated and holds the handle. The caregivers hold their handles and impose the stand-up motion of the patient.
Typical measurements of the interaction forces on the wrist during a sit to stand transfer are detailed in the following curves (Figure 8) for the Y and Z axis directions (forces in the sagital plan) which are the most interesting directions for our design procedure. The torques values are, as expected, very low and are not shown in this paper.

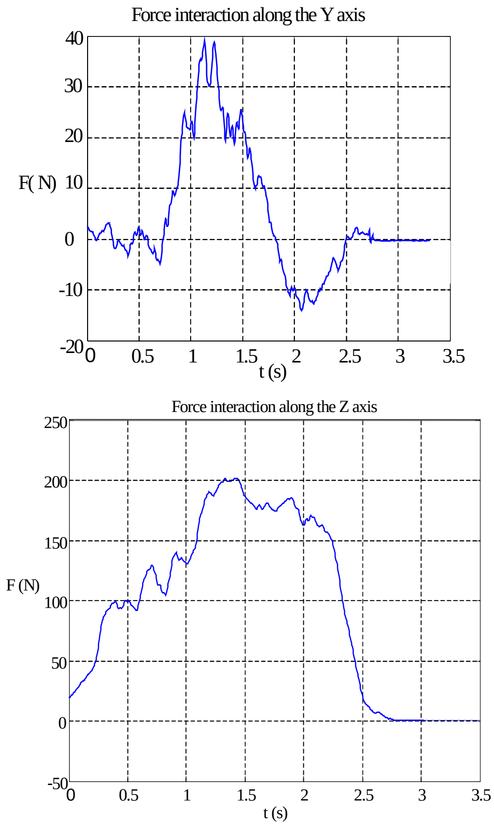

Figure 8. Force applied on the handle

The maximum support force (along the Z direction) recorded during this field test experiments are between 160 and 220 N, depending on patients. These values are of the same order of magnitude than those reported in [10] for a power-assisting device for self-transfer of patients.

Typical measurements of the patient trajectory handle are given Figure 9. On this record, the zero is at 500 mm over the ground level.

The minimum lower bound and maximum upper bound of the handle trajectory as well as the maximum support force recorded for the set of elderly patients will be used in the optimization process to define the proper values of the link lengths and of the actuator capacity (see section 3.3).

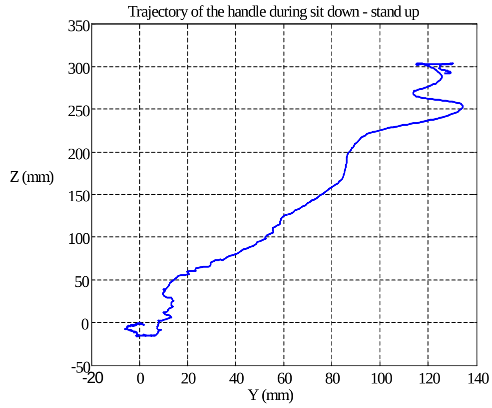

Figure 9. Trajectory of the handle

The whole handle trajectory will be used in future work to define the joints (handle elevation and displacement of the two back wheels) trajectory of the walking aid.
The measured position and orientation of the user torso have also been recorded (not shown in this paper). These measurements will be useful for the virtual human model used in section 3.4.

3.3 Dimensions optimization

The optimization problem consists to find the dimension of the links for a good force transmission.

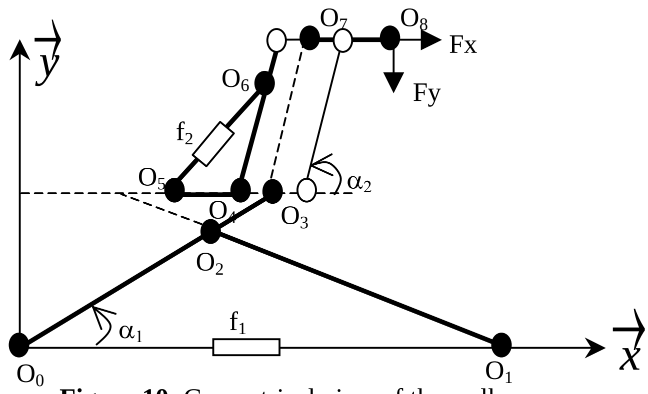

Figure 10. Geometrical view of the walker

The model of the mechanism force transmission is $[f]=[J]^t[F]$, where $[f]$ is the vector of the actuator forces, $[F]$ is the vector of the forces applied on the handle and $[J]$ is the jacobian matrix of the mechanism.
The link lengths are the parameters to be searched:
X(2)= O_1O_2, X(3)= O_2O_3, X(4)= O_4O_6, X(5)= O_4O_5, X(7)= O_3O_7, X(8)= O_7O_8, X(9)= O_0O_2, and X(1)=O_0O_1 (the wheel linear advance), X(6)= O_5O_6 the joint variables.
The position of the walking-aid handle in the plane $(O_0,\vec{x},\vec{y})$ expressed with these parameters is:

$$(1)\begin{cases} X=(X(2)+X(3))\left(\frac{1-T_1^2}{1+T_1^2}\right)+X(7)\left(\frac{1-T_2^2}{1+T_2^2}\right)+X(8) \\ Y=(X(2)+X(3))\left(\frac{2T_1}{1+T_1^2}\right)+X(7)\left(\frac{2T_2}{1+T_2^2}\right) \end{cases}$$

$$\text{with } (2)\begin{cases} T_1^2=\tan^2\left(\frac{\alpha_1}{2}\right)=\frac{X(9)^2-(X(1)-X(2))^2}{-X(9)^2+(X(1)+X(2))^2} \\ T_2^2=\tan^2\left(\frac{\alpha_2}{2}\right)=\frac{X(6)^2-(X(5)-X(4))^2}{-X(6)^2+(X(5)+X(4))^2} \end{cases}$$

The Jacobian of the walking-aid in the plane connects the velocity of the handle and the actuator velocity:

$$\begin{bmatrix} \dot{X} \\ \dot{Y} \end{bmatrix}=\begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix}\begin{bmatrix} \dot{X}(1) \\ \dot{X}(6) \end{bmatrix}$$

$$(3)\begin{cases} J_{11}=\frac{-(X(2)+X(3))}{X(1)X(2)}\left(X(2)\left(\frac{1-T_1^2}{1+T_1^2}\right)-X(1)\right) \\ J_{12}=\frac{-X(7)X(6)}{X(4)X(5)} \\ J_{21}=\frac{(X(2)+X(3))(1-T_1^2)(X(2)(1-T_1^2)-X(1))}{2T_1\,X(1)X(2)} \\ J_{22}=\frac{X(6)X(7)(1-T_2^2)}{2T_2\,X(4)X(5)} \end{cases}$$

The geometrical parameters for a good force transmission mechanism verify:

Min([f]^t[f])

For a position of the handle

The objective function of the optimisation process is:

- $[func(X(i))]=[F]^t[J][J]^t[F],\ i=1..9$, knowing the external forces for a position of the handle.

The linear inequality constraints are:

- X(i)>0, I=1..9, all the lengths are positives
- The back wheel is forward the projection of the handle : X<X(1) (to have the center of gravity projection in the sustentation polygon)

The nonlinear equality constraints are:

- The direct kinematic model: equations (1) and (2) (for the upper and the lower positions)

The link lengths, solution of the optimization process, are given below:
Upper position:
X=[102.75, 31.21, 13.45, 5.1, 3.02, 28.78, 24.88, 12.2, 40.11]
Lower position:
X=[119.98, 31.21, 13.45, 5.1, 3.02, 22.14, 24.88, 12.2, 40.11]

With the measure of the trajectory and the force interaction of the user during sit to stand transfer, we can calculate the maximum forces exerted by the actuator. This is done using the Principle of Virtual Work:

$$\begin{bmatrix} Weight \\ external\,F \end{bmatrix}^t\begin{bmatrix} \dot{X}\ \dot{Y} \end{bmatrix}+\begin{bmatrix} f_1 \\ f_2 \end{bmatrix}^t\begin{bmatrix} \dot{X}(1)\,\dot{X}(6) \end{bmatrix}=0$$

Then, the maximum value according to the experimental input is:

f_1=400N and f_2= 130N

These values are used to define the capacity of the actuators.
With these geometrical dimensions and actuator capacities, we may simulate the behaviour of the interaction between human and walking-aid. The aim of this simulation is to evaluate the device efficiency and to analyse the mechanism behavior under some parameters modifications.

4 Acknowledgements

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5 Conclusion

A preliminary design of high stability robotic system used to assist elderly people has been presented.
The overall kinematics definition of this device was based on an analysis of the most common walking trouble associated with aging. The optimal links lengths and actuators capacity of this device have been calculated using experimental measurements of the hand motion and interaction forces recorded during aided sit to stand transfer of elderly patients.

The next step will be the building of a prototype. It will be equipped with force/torque sensors mounted on the handles and with a force based controller to provide an intuitive man/machine interface
First of all, this device is expected to be useful for giving elderly patient more autonomy since it will provide support for both sit to stand transfer and for walking.
This device can also be a useful tool for physicians and gerontologist to better understand walking troubles and

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to prevent falls as well as a powerful programmable device for rehabilitation of the lower limbs.

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