# Design of an active walking-aid for elderly people

Pascal Médéric, Viviane Pasqui, Frédéric Plumet, Philippe Bidaud

DRAFT

# Design of an Active Walking-aid for Elderly People

P. Médéric, V. Pasqui, F. Plumet and Ph. Bidaud
Laboratoire de Robotique de Paris
BP 61, Fontenay-aux-Roses, France
E-mail {mederic, pasqui,plumet,Bidaud}@robot.jussieu.fr

## 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 has also to be adapted to the morphology and/or 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 certain 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 and techniques have been investigated in a recent past to prevent falls by a postural control of patients and to promote safe mobility ([5], [6], [7]). In this context, the system we have designed (see Figure 1.) focuses on two main problems related to postural control: (1) sit to stand transfer, (2) walking stability.

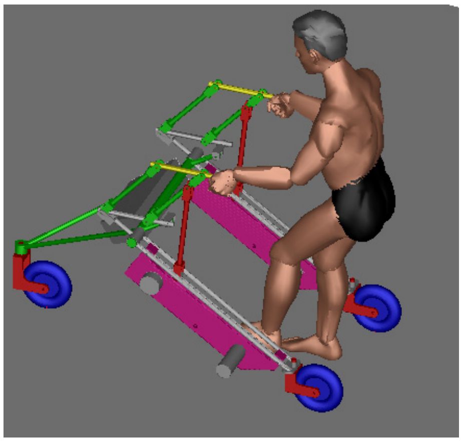

**Figure 1.** An active walking-aid for elderly people

It can be seen as an active mechanical interface. The proposed paper describes the design process of such system. We first clarify the mechanical behaviour of the human body during standing and walking as well as the disturbances induced by some particular pathologies. This analysis, associated with forces and trajectories data capture, constitutes the input of the design process. Then, we will describe the topological and dimensional synthesis of an active mechanism used for the posturology control.

## 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 lower limb

Rehabilitation exercises after surgery of lower limb needs to be done as soon as possible. That implies nurse staff 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 could set 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

Elderly people who had fall can be affected by the syndrome of “post-fall”. 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, conducts 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.

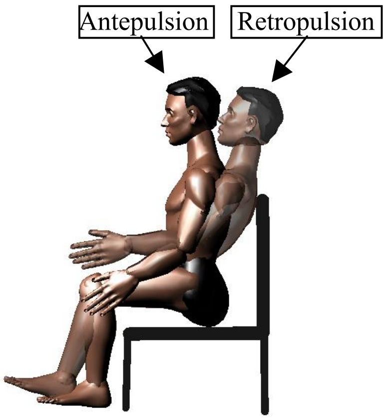


**Figure 2.** Antepulsion and Retropulsion postures

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 are not between the two feets. The configuration does not guaranty 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 robotic device which will help elderly in two physiological functions:

- ✓ Sit to stand transfer
- ✓ Stability during walking

## 3 Design System

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

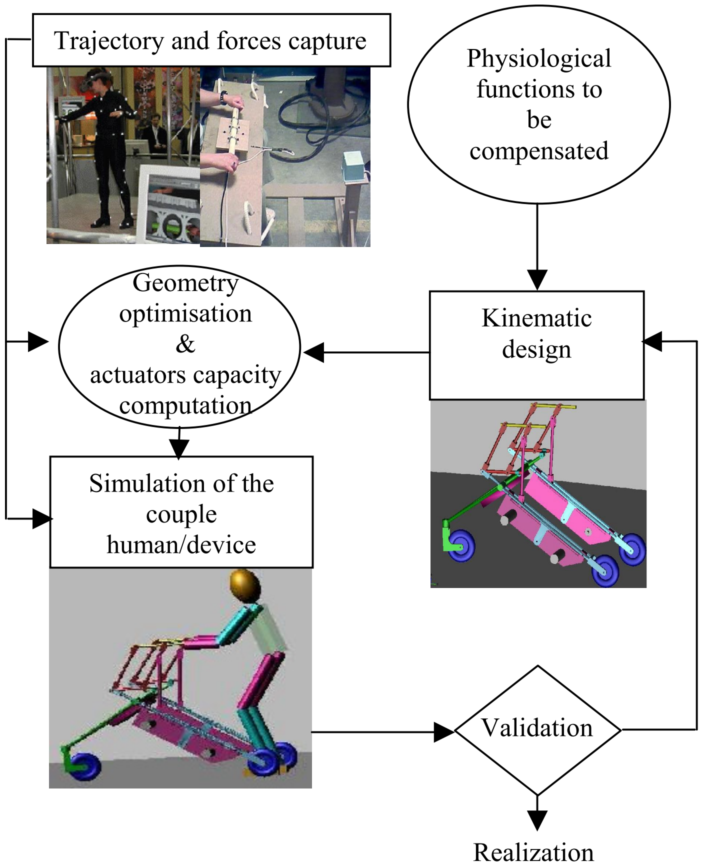


**Figure 3.** Design procedure

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

1. **Kinematic design** is done from the analysis of the complex mechanical functions compensating the physiological function injured and taking into account the constraints upon the elderly (morphology, pathology).

2. **Geometrical parameters** optimisation and actuators capacity are defined from the computation of models that needs experimental measures as data entries.
3. **Dynamical simulation** of the couple elderly/system is used for an evaluation of the mechanical design

### 3.1 Kinematic design

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, such as the back wheels positions are always behind the feet. Then, 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. The first condition for a stable walking is then verified.

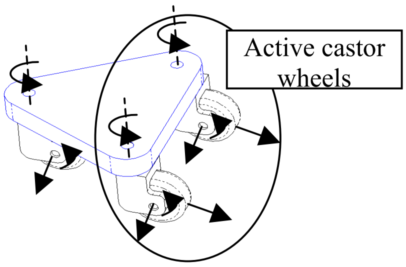


**Figure 4.** Holonomic wheeled-platform

The device may also assist elderly in the sit to stand transfer.
To be lift softly, the handlers have to pull slowly the elderly in an antepulsion configuration: two degrees of freedom are needed and the handlers must remain horizontal, that is made of two parallel mechanisms combined in a serial way (passive four bars linkage and “balancier d’Evans”), as illustrated in Figure 5.

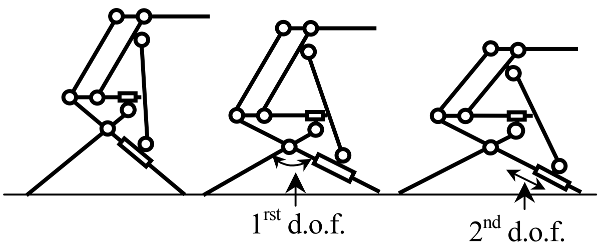


**Figure 5.** Handlers mechanism

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

The whole mechanism is a combination of the ones describe before with the following motorization:

- The two back wheels and their direction are motorized.
- The handlers motion are driven by linear actuators.

This kinematics is illustrated in Figure 6.

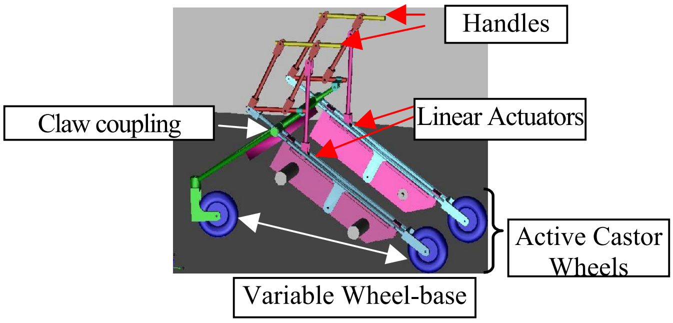


**Figure 6.** Kinematic of the walking aid.

In the second part of our design procedure, we must find the optimal dimensions of the mechanical structure. This procedure is based on the sit to stand transfer analysis.
During the sit to stand transfer, the arms handles have to follow the hands trajectory while being able to produce enough forces to balance the patient. To have a valuable insight into the trajectory and the handling forces along the trajectory, we used the experimental device depicted in Figure 7.

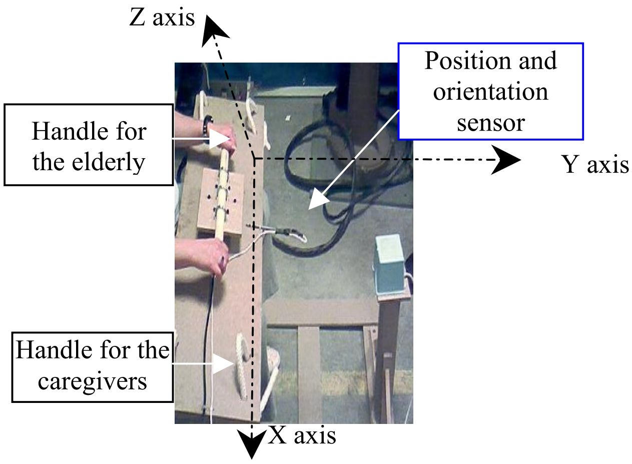


Figure 7. **Trajectory and force transmission capture**

The test platform is composed of two handlers for the two caregivers and an handler, mounted on a 6 axis force/torque sensor. Two 6 axis position/orientation sensors are also used to monitor the patient handler and the patient torso positions. This device can then be used to simultaneously record the forces and trajectory during a sit to stand transfer.

Experiments has been conducted on a set of elderly patient in Charles-Foix Hospital.

For these experiments, the patient is sit-down and hold the handler. The caregivers hold their handlers 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.

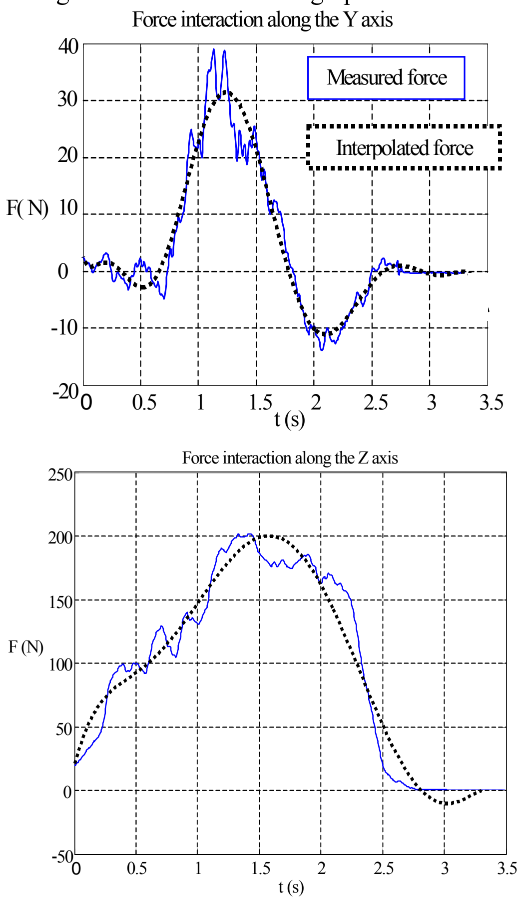


**Figure 8.** Force applied on the handler

As expected, the torques values (not shown in this paper) are very low.
These measures quantify the maximum forces on the patient handlers. They will be used in the static model to compute the maximum actuator forces (see section 3.2).
Typical measurements of the patient trajectory handler is given Figure 9. The handler motion define, through the kinematic transformation, the handler elevation and the displacement of the two back wheels. These joint trajectories will be used for the control of the walking aid.
The lower and upper bounds of the handler trajectory are also used in the optimization process to define the proper values of the link lengths (see section 3.2).

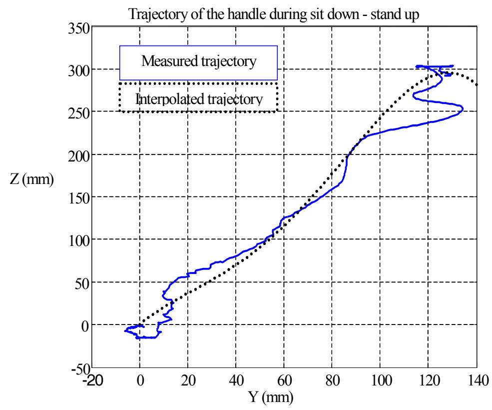


**Figure 9.** Trajectory of the handler

The measured position and orientation of the users' torso have also been recorded (not shown in this paper). These measurements will be useful for the virtual human model used in section 3.3.
The handler trajectories, recorded for a set of elderly patients, define the operational workspace of the walking aid. In order to properly design our walking aid we now search the optimal values for the geometry of the structure such that the operational space trajectories belongs to this workspace.

### 3.2 Dimensions optimisation

The data entries are the handler position noted H in the simplified geometrical definition of the mechanical system presented Figure 10.

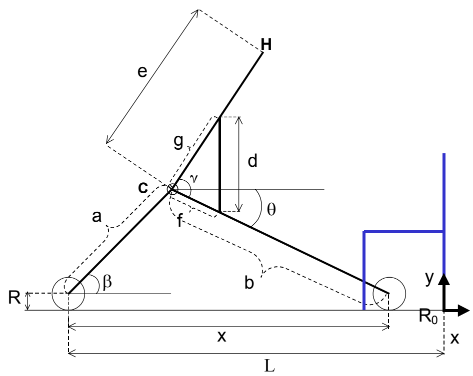


**Figure 10.** Geometrical parameters of the walker.

The H position may be expressed as a function of the geometrical parameters of the mechanical structure:

$$(E1)\quad \begin{cases} H_x = -l + a\cos(\beta) + e\cos(\gamma-\theta) \\ H_y = R + a\sin(\beta) + e\sin(\gamma-\theta) \end{cases}$$

With

$$(E2)\quad \begin{cases} \cos(\beta) = \dfrac{x^2+a^2-b^2}{2ax} \\ \cos(\gamma) = \dfrac{f^2+g^2-d^2}{2fg} \\ \cos(\theta) = \dfrac{x-\cos(\beta)}{b} \end{cases}$$

The objective functions of the optimisation process are:

- F1: the upper position of the handler
- F2: the lower position of the handler

The set of parameters to be optimised is:

$$X=[a, b, d, e, f, g, x]^t$$

These objectives functions are constrained by the following considerations:

- ❖ All elements of X must be positives
- ❖ The structure must not becoming flat
- ❖ The system should not touch the floor
- ❖ The user should be able to make a step forward after stand up
- ❖ The cross-bar pulling on the arm must be as near as possible than the handler
- ❖ The cross-bar pulling on the arm must be vertical in the up position
- ❖ The angle between the four bar linkage (in up position) and the horizontal axis : $\gamma-\theta \leq \pi/2$
- ❖ The overall dimensions in up position for the linear actuator prescribes: $f-b/3 \leq 0$ and $R-f \leq 0$ (R is the radius of the back weel)
- ❖ The overall dimensions in down position for the linear actuator prescribes: $2b/3-f \leq 0$ and $R+f-b \leq 0$

To do the optimisation we used MATLAB™ functions in the algorithm presented Fig.11.

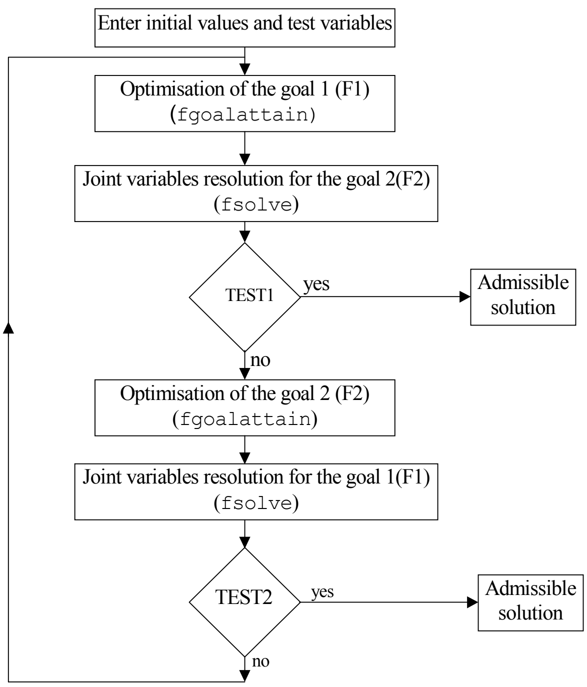


**Figure 11.** Optimisation algorithm

For both the up and down positions, the optimised parameters obtained must have the same value except for f and x which are the joint variables.

The link lengths, solution of the optimisation process, are given below:.

**Upper position**:

X=[ 65.015 , 88.13 , 39.89, 43.14 , 12.65, 34.51 , 116.14]

**Lower position**:

X=[ 65.015 , 88.13 , 39.89, 43.14 , 59.81, 34.51 , 144.26]

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 Works:

$$\vec{F}\delta x + \vec{\tau}\delta q = 0 \text{ With } \delta x = J\delta q$$

where J is the Jacobian matrix of the simplified structure describes Figure 12.

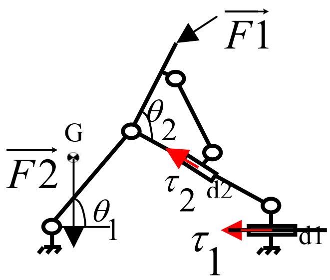


**Figure 12.** Equivalent static structure

The value of the unknown actuator forces $\tau_1$ and $\tau_2$ are given by :

$$\tau = J^t F$$

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

$$\tau_1=400\text{N} \text{ and } \tau_2= 130\text{N}$$

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.

### 3.3 Evaluation

For the dynamic simulation of the walking aid coupled with an human virtual model we use visualization and modelling software ADAMS™/VIEW and its plug in LifeMod for the human dummy (see Figure 13).

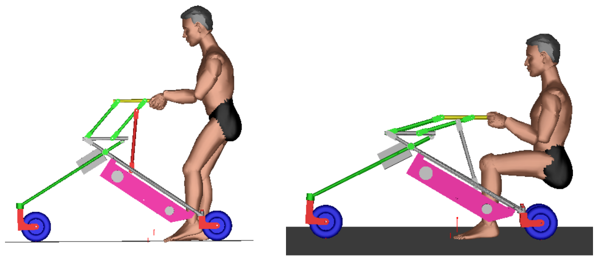

**Figure 13.** Couple Elderly/walking-aid

The dynamical simulation done by ADAMS provides that the mechanism help the virtual model of Elderly to stand up or sit down.

## 4 Acknowledgements

This work was in part supported by the french RNTS (Réseau National des Technologies de la Santé) program under grant N° 02B0414 (Monimad Project)

## 5 Conclusions

A preliminary design of high stability robotic systems used to assist or to rehabilitate the Elderly has been presented. The mechanism presented in this paper scoped with two objectives. In the one hand, it is the first step towards the design of a smart walker and, on the other hand, it is a tool for an experimental platform aimed at measuring the behaviour of the elderly frail. Data obtained by these measures are currently used in the procedure of designing similar devices.

## 6 References

[1] Perrin Ph., Perrin C., "Exploration des afférences sensorielles et du contrôle moteur de l'équilibration par la posturologie statique et dynamique", *Ann. Otolaryngol. Chir. Cervicofac*. N°60, pp.113-146, 1996.

[2] Association ORION, « Le système tonique postural », (http://www.chez.com/orion/cours1.htm)

[3] Gagey P.M., Bizzo G., Ouakkine M. and Webber B., "Deux modèles mécaniques de stabilisation posturale : la tactique du centre de gravité et la tactique du centre de pression", *2nd International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines*, Portsmouth, U.K., Professional Engineering Publishing Limited, 1999.

[4] Kemoun G., "Physiologie de la marche Particularité chez la personne âgée », *La chute* N°59, 2éme Trimestre 2001, Association Nationale des Médecins spécialistes de rééducation. Médecine Physique et de réadaptation (http://www.anmsr.asso.fr/anmsr00/59/kemoun.htm)

[5] Lacey G., Dawson-Howe K.M., »The application of robotics to a mobility Aid for the Elderly Blind », Robotics and auto. Systems, N°23, pp. 245-252, 1998.

[6] Dubowsky S., Genot F., Godding S., Kozono H., Skwersky A. Yu H. and Yu L., "PAMM – A Robotic aid to the Elderly " , IEEE international Conference on Robotics and automation, 2000.

[7] Lee C., Kim K., Oh S. and Lee J., "A system for gait rehabilitation : mobile manipulator approach", Proc. 2002 IEEE International Conference on Robotics and Automation, pp. 3254-3259, 2002.