Characterization of a least effort user-centered trajectory for sit-to-stand assistance

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Abstract Sit-to-stand transfer is a prerequisite for locomotion and induces a lot of effort from elderly or disabled people. In the context of a project based on a locomotion and sit-to-stand assistance robotics device, we present a methodology to tune the trajectory of active handles so that the verticalisation effort of the user is minimised. The methodology is user-centered in the sense that the robot will generate a specific trajectory for each particular user.

1 Introduction

A robotic device to assist the locomotion function of elderly and disabled people may improve a lot their autonomy, the efficacy of rehabilitation efforts and, more generally, may improve their quality of life. But assisting locomotion is of less interest if it does not help the user in transfering himself or herself from the sitted position to the standing position. As a matter of fact, very few robotics systems are endowed with both a locomotion assistance and a verticalisation assistance capability [7], [1], [11]. However the sit-to-stand motion induces a lot of effort from the patient. Thus it is of the most importance to design the robotic assistance device so that this effort is minimised.
In this paper, we present a preliminary study of a user-centered methodology that is designed to generate an assistance trajectory for robotic handles that minimises the effort from the user depending on his/her own sit-to-stand transfert strategy.
The generated trajectories are tailored to a particular user using a set of five parameters:

- P_I and P_F, the initial and final positions of the trajectory, are chosen by the user,

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- T_F, the sit-to-stand transfert time, is set by the experimenter,
- (dev_1, dev_2) describe the shape of the trajectory, they must be different for each user. Our method tunes dev_1 and dev_2 so as to minimise the effort.

The paper is organised as follows. In Section 2, we present Monimad, the robotic assistance device that we use, as well as our method to generate trajectories. In Section 3, we describe our method to choose among five trajectories the one that is most adequate for a particular user, and then our method to tune dev_1 and dev_2 depending on the user effort. In Section 4, we present the preliminary empirical results that we obtained with the method. These results are discussed in Section 5 before we conclude.

2 Robotic device

Monimad is an original assistive device, combining sit-to-stand transfer and walking aid for elderly and disabled people. It allows mobility rehabilitation and assistance, safe walking (postural stabilization) and safe sit-to-stand transfer [11]. The designed robotic system is basically a two degrees of freedom arms mechanism mounted on an active mobile platform (Fig. 1). The lower part (mobile platform) consists of two electric motors actuating the wheels. The upper part of the mechanism (articulated arms) consists of two plane parallelograms to maintain the handles horizontally, actuated by linear actuators. In addition, they are independent in order to restore lateral balance. The end effectors consists of handles equipped with a six axis forces/torques sensor that are used in the experiments presented below to evaluate the relevance of the sit-to-stand trajectory. A preliminary analysis of the

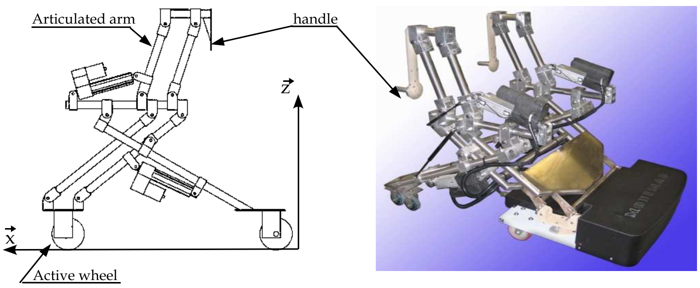

Fig. 1 Description of Monimad a Robotic assistant for sit-to-stand and walking

movement in elderly sit-to-stand clinical trials, with a specific measurement system [11], has allowed to describe the trajectory of the hands during assisted movements. First, the handles must pull slowly the patient to an antepulsion configuration (see Fig. 2). Then, they go from this down position to the up position, used for walking. For each patient, several sit-to-stand transfer trajectories were recorded, some

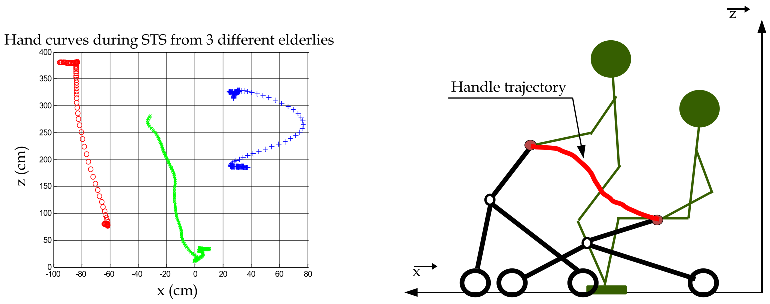

Fig. 2 Experimental sit-to-stand transfer trajectories

examples of these trajectories are given in Fig. 2. The analysis of these transfer trajectories shows that the global shape of the trajectory is a ”s-like” curve and is not directly related to the age or height of the patient but seems to be correlated with its own personal strategy to stand up or sit-down. This seems to reflect invariants of the trajectory generation [14]. The trajectory of the handles has to be similar to the general curve presented in Fig. 3. The term ”trajectory” refers here to Cartesian-space

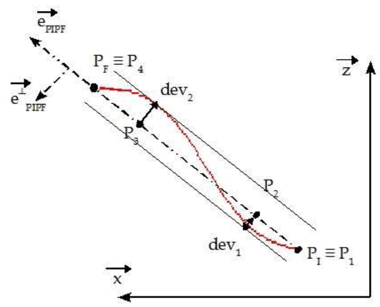

Fig. 3 The handles trajectory in cartesian space. This kind of curves look like a third order polynom in the $(P_i, \mathbf{e}_{P_iP_f}, \mathbf{e}^{\perp}_{P_iP_f})$ frame. The input of these curves are the initial and final handles positions (P_i and P_f) and the curvatures of both pieces of the curve (dev_1 and dev_2).

planning of the handle movement. A ”natural” trajectory is requested for comfortable human movement assisted by robotic devices. From our point of view, ”natural” means that the trajectory path must be compatible with hand movements when the sit-to-stand transfer is assisted by someone else. It must also be smooth and generate a continuous motion of the hand. As proposed in [15], smoothness can be quantified as a function of jerk, which is the time derivative of the acceleration.

The method to obtain such a trajectory consists in decomposing its characteristics into a physiological part and a mechanical part. The minimum jerk criterion is a physiological constraint for smoothness and is only related to trajectory quality. Thus, the curvilinear abscissa is used to describe the law of motion satisfying the minimum jerk criterion.

Let $s(t)$ represents the distance that the handles have moved along the curve at instant t. The curvilinear abscissa $s(t)$ defined by Eq. 1 (see [15]), guarantees the smoothness of the handles trajectory.

$$s(t)=s(T_i)+(s(T_f)-s(T_i))(10(\frac{t}{T_f-T_i})^3-15(\frac{t}{T_f-T_i})^4+6(\frac{t}{T_f-T_i})^5) \quad (1)$$

Where T_i is the initial time and T_f is the final one.
The geometrical path describing the hand are not time dependent and may be expressed in terms of Euclidean coordinates. An assisted sit-to-stand transfer trajectory follows a path similar to the one shown in Fig. 3.
This kind of curve will be defined by a third order polynomial in the $(P_i,\mathbf{e}_{P_iP_f},\mathbf{e}^{\perp}_{P_iP_f})$ plane (with : $\mathbf{e}^{\perp}_{P_iP_f}=\mathbf{z}\wedge\mathbf{e}_{P_iP_f}$). Considering the point P_j on the handle path curve: $\mathbf{P_iP_j}=U_j\mathbf{e}_{P_iP_f}+V_j\mathbf{e}^{\perp}_{P_iP_f}$, with : $V_j=\sum_{i=0}^{3}\alpha_iU_j^i$. The knowledge of the coordinates of the points P_k ($k=0,\dots,4$, Fig.3) leads to the equations below:

$$\begin{cases}\alpha_0=0 & \\ \alpha_1U_1+\alpha_2U_1^2+\alpha_3U_1^3=V_1\ (=dev_1) & (A)\\ \alpha_1U_2+\alpha_2U_2^2+\alpha_3U_2^3=0 & (B)\\ \alpha_1U_3+\alpha_2U_3^2+\alpha_3U_3^3=V_3\ (=dev_2) & (C)\\ \alpha_1U_4+\alpha_2U_4^2+\alpha_3U_4^3=0\ (where\ U_4=\overline{P_iP_f}) & (D)\\ \left(\frac{dV}{dU}\right)_{U_1}=\alpha_1+2\alpha_2U_1+3\alpha_3U_1^2=0 & (E)\\ \left(\frac{dV}{dU}\right)_{U_3}=\alpha_1+2\alpha_2U_3+3\alpha_3U_3^2=0 & (F)\end{cases}$$

A solution of this system is obtained in two steps. First, solving the linear system $\{(A),(B),(C)\}$, α_i coefficients can be expressed in term of U_1,U_2,U_3. In a second step, U_1,U_2,U_3 values are the solutions of the minimisation problem based on equations $\{(D),(E),(F)\}$ defined as:

$$min((D)^2+(E)^2+(F)^2)\text{ under }\begin{cases}-U_1<0\\ U_1-U_2<0\\ U_2-U_3<0\\ U_3-U_4<0\end{cases} \quad (2)$$

The starting point of the optimization procedure, is taken such that:

$$\begin{cases}-U_1<2\%\text{ of the length curve }(s(T_f)-s(T_i))\\ U_1-U_2<2\%\text{ of the length curve}\\ U_2-U_3<2\%\text{ of the length curve}\\ U_3-U_4<2\%\text{ of the length curve}\end{cases} \quad (3)$$

We have observed that the resulting polynomial is always very close to the experimental curve. The handle trajectory in spatiotemporal space is defined by U and V coordinates as time functions, such that

$$(\frac{dU}{ds})^2+(\frac{d}{ds}(\sum_{i=1}^{3}\alpha_iU^i))^2=1$$

Finally, the trajectory is a time function of Cartesian coordinates generating a smooth movement. Estimated coordinates of the point P are computed with the following recursive scheme:

$$\begin{cases} U(k+1) = \frac{(t(k+1)-t(k))(4\dot{s}_M \cdot t(k)\cdot(T_f - t(k)))}{(T_f^2\sqrt{1+(\sum_{i=1}^{3} i\alpha_i U(k)^{i-1})^2})} + U(k) \\ V(k+1) = \sum_{i=1}^{3} \alpha_i U(k+1)^i \end{cases} \quad (4)$$

And $\dot{s}_M$ is computed with the handle path length using simultaneously the curvilinear abscissa and the Euclidean coordinates:

$$\dot{s}_M = \frac{3(\sum_{i=0}^{N}\sqrt{(U_{i+1}-U_i)^2+(V_{i+1}-V_i)^2})}{2T_f} \quad (5)$$

In order to observe the posture of the user, a six axis force/torque sensor is placed under the user's feet to measure the ground contact forces and the forces applied to the handles. As a consequence, the anticipatory postural adjustement (APA) determination can be used to initiate the sit-to-stand motion of the robot handles. Both ground and hand forces, treated with fuzzy logic laws, give information on the sit-to-stand transfer phase and on the stability state of the user [16].

3 Experimental study

The goal of our experiment is to tune the dev_1 and dev_2 parameters of the trajectory so as to ensure that the user makes as few effort as possible. Our methology consists of three steps:

- First, we recorded the global effort of the users along a set of five trajectories that have been shown through clinical experiments to provide a satisfactory basis for sit-to-stand assistance trajectory generation [14]. The active handles are controlled in position, than the user has no other choice then following the imposed

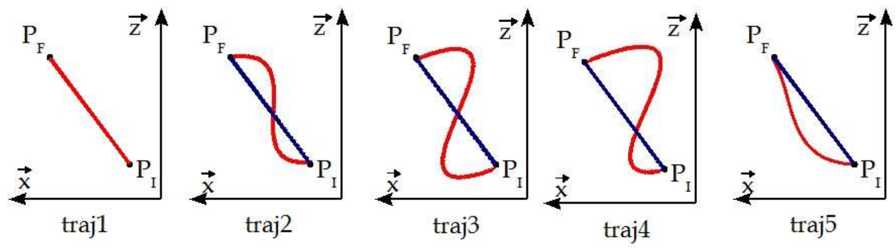

Fig. 4 Trajectories for experiments

trajectory. The difference between the natural trajectory the subject would use if helped by a human assistant and the imposed trajectory generates an additional effort from the user. Thus we assume that the most natural trajectory is one that generates the least global effort from the user.

- In a second step, we control the active handles with some impedance, so that the user can locally alter the handles trajectory. We assume that the subject will alter the handles trajectory so as to make it more comfortable, provided that the corresponding additionnal effort is not too high.
  The altered trajectory corresponds to modified dev_1 and dev_2 parameters that can be extracted from this second step [17].
- In the third step, we record again the total effort of the user with a position controlled handles trajectory, where the trajectory is generated according to the dev_1 and dev_2 values determined in the second step. We check that the global effort is smaller than initially.

4 Results

The experiments were performed with 8 subjects. All were healthy male volunteers between 25 and 30 years old (average: height :175,3 $\pm$ 5,36 cm,
weight : 66,2 $\pm$ 9,91 kg). They were instructed to stand-up as naturally as possible. Every subject performed 10 sit-to-stand tranfers. The data corresponding to one subject has been discarded as inconsistent.
Among the subjects, three select traj5 in Fig. 4, two select traj2 and, traj1 and traj3 are selected by one subject.
These trajectories are the least deformed when the verticalisation is made with the active handles controled with an impedance law. That is that among the proposed trajectories, the one that is followed most closely is the one where the sum of efforts measured at the hands and at the feet are the least. The new parameters dev_1, dev_2 are determined from the average of ten sit-to-stand trajectories recorded, when the active handles are controled with an impedance law.
Now these trajectory are used again with the active handles controlled in position. Fig. 5 shows, for one subject, that the resulting trajectory is not deformed a lot, so validating the hypothesis according to which the most comfortable trajectory is the one which brings the least effort.

5 Discussion

The fact that different subjects select diverse trajectories among our basis of five trajectories reveals the importance of a user-centered approach.
Indeed, given that each subject has his own sit-to-stand transfer strategy, any methodology that would propose an unique trajectory as optimal for all the subjects

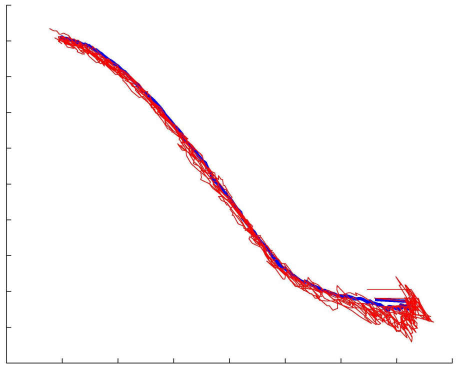

Fig. 5 The blue trajectory is made with the active handles controlled in position and the red ones are recorded when the active handles are controled with an impedance law

would fail to take their specificities into account and would generate unnecessary effort and discomfort for some of these subjects.

Second, the fact that our method effectively results in a global decrease of effort for all subjects is encouraging. However, we cannot claim for any of the subject that we have found the trajectory that would minimize his effort. To further optimize the dev_1 and dev_2 parameters, we will call in the future upon gradient descent approaches that are guaranteed to reach at least a local optimum, provided enough data.

6 Conclusion and future work

In this paper, we have presented a preliminary methodology that validated the feasability of minimising the effort of users in the context of robot-assisted sit-to-stand transfert. The method shapes the active handles trajectory just by tuning two parameters, dev_1 and dev_2. Immediate future work will consist in calling upon gradient descent tools to further optimize the parameters. Then, the next step will consist in incorporating the method in the broader context of our robotic-assisted locomotion project and, in parallel, in evaluating its benefits with elderly and disabled patients.

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