

Collaborative control for personalized mobility assistance to persons with physical/cognitive disabilities

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I. COLLABORATIVE ASSISTED CONTROL: MOTIVATION AND PROPOSAL

People with disabilities may require some kind of assistance, either from a machine or from other persons, for mobility. For most robotized wheelchairs, assistance usually consists on offering a limited amount of non personalized help, like collision avoidance mechanisms (safeguarded cooperation) [1] [2], or on taking over either when hazardous situations are detected or at the user's will (shared control) [3] [4] [5]. Situations where machines and persons cooperate to achieve a common goal fall within the field of collaborative control. It has been reported by doctors that lack of participation of people in conducting certain activities lead to loss of residual capabilities. Furthermore, participation and feedback is reported as to enhance rehabilitation.

We propose a new approach consisting of combining both the machine and the human orders at every moment in a cooperative way. Our approach relies on evaluating the performance of human and machine driving for each given situation using local metrics, meaning that only local factors are estimated to rank their performances. Then, human and robot control is combined at reactive level, by adding their motion commands as vectors, weighted by their corresponding efficiencies (Fig.1). The emergent behavior produces a trajectory which follows the user's commands but it is modulated by the robot. The main novelty of the proposed approach is that both human and robot collaborate in motion control all the time rather than switching it under given circumstances.

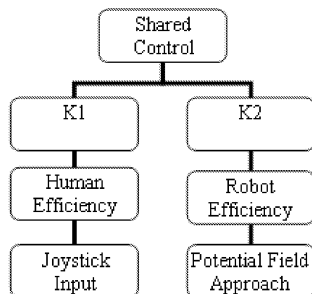


Fig. 1. System Architecture

Since human (h) and robot (r) cooperate at reactive level, we have chosen to use a Potential Fields Approach (PFA) to calculate the robot command, despite its well known drawbacks. These drawbacks will be reflected in weights lower than one in many cases for the robot. The user command is extracted from the joystick input at each time instant. The shared output trajectory at position p is obtained as:

$$U(p) = K_h w_h \text{Joys}(p) + K_r w_r \text{PFA}(p) \quad (1)$$

The weight of the joystick and the robot (w_h and w_r) is a function of their local efficiencies in terms of smoothness, safety and directiveness, estimated as:

$$E = \frac{k_1 e^{-C_1 \cdot \frac{1}{d_{min}}} + k_2 e^{-C_2 |\alpha_1|} + k_3 e^{-C_3 |\alpha_2|}}{k_1 + k_2 + k_3} \quad (2)$$

K_h and K_r are fixed either to 0.5 both, so that control is equally shared by human and robot, or to 1 and 0 respectively, so that the human drives on his/her own. They are meant to be used in a future to modulate shared control via upper level algorithms that may take into account medical state, caregivers' prescriptions, etc. E is calculated both for the robot PFA output command and the joystick output to obtain w_r and w_h , respectively.

k_i are weights that settle how important each of the factors is for global efficiency (initially, all k_i are equal). Similarly, C_i weights the slope of the importance of each factor with respect to the baseline value. For example, if k_1 is high, getting away from obstacles is more important than keeping a smooth trajectory. If C_1 is high, though, such a factor begins to be strong when obstacles are quite close, but it is not so important when they are mildly away. d_{min} is the minimum distance to obstacle detected by onboard range sensors. It is measured with respect to the proposed output heading, so that trajectories leading to that obstacle rank lower. α_{goal} is the angle difference between the output heading and the direction to the goal, representing that it is better to reach the goal following a straight line in terms of trajectory length. α_{head} is the angle difference between the output and input heading, representing that sharp turns should be avoided for safety and to minimize slippage. All mentioned factors are reflected in Fig. 2 for human and robot.

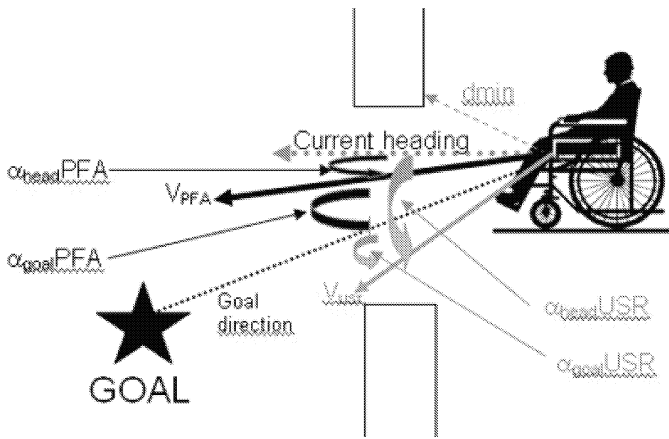


Fig. 2. Local efficiency factors for human and robot

II. SCENARIO AND METHODOLOGY

The following tests consist of checking the combined performance of human and robotic control in driving a wheelchair in a real hospital in Rome: Fondazione Santa Lucia ¹(FSL). Tests were performed using a commercial Meyra wheelchair equipped with a laser and wheel encoders (Fig. 3.a). The joystick of the chair had been replaced with another one that derived the commands to an onboard industrial PC before sending it to the motors. The PC modified the joystick commands to provide assistance. All tests were conducted with volunteers that presented different degrees of physical and/or cognitive disabilities. There was a doctor present at all times and, for these experiments, the hall where the patients moved was isolated from non authorized people. PFA were adjusted to grant a minimum distance to obstacle approximately equal to 20 cm to allow door crossing. If obstacles were detected closer than this distance, an underlying safety layer stops the robot.

Experiments consists either on trying to follow a straight line, free of any obstacle, with the chair -either alone or with assistance-, or alternatively on following the trajectory deployed in Fig.3.b on any of the two possible directions.

The goal of these experiments is to check if the system is capable of adapting assistance to the user's needs at each moment. If this is the case, performances for different patients should be similar despite their different diagnoses, plus they

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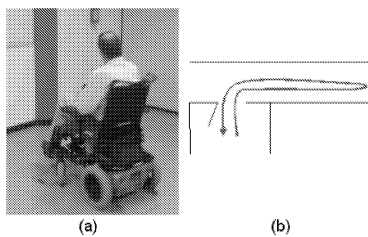


Fig. 3. a) Modified wheelchair; b) test goal paths

should not note too much that they are receiving assistance. As a second target, we wanted check if shared control improves the drive learning process. Hence, we measure the amount of help provided to the user in each trajectory, his/her stand-alone efficiency, the time required to finish the trajectory and asked about the subjective degree of satisfaction of each user.

III. EXPERIMENTS AND RESULTS

A total of 30 patients took part in the experiments at FSL on July, 16-22 2007. All of them volunteered to drive the chair according to the trajectories in Fig. 3 and their traces and related efficiencies and commands were recorded all the way. No moving obstacles were included in the trajectories at this point. In order to globally measure the users' performance as simply as possible, their average efficiency was calculated through all the trajectories, along with the efficiency of the wheelchair on its own and the shared efficiency when collaborative control was allowed. Another metric that can be of use is to compare the local efficiency E (Eq.2) of PFA and human in a trajectory with and without assistance (Fig.4). Fig. 4.a represents the ratio between E_r and $E_{joystick}$ in a test without assistance ($K_h=1, K_r=0$) in two different consecutive trajectories, minus door crossing (we did not want to check door crossing without assistance). It can be observed that the robot is typically better than the human; especially in the initial stage of the trajectory (this patient seems to control better the chair after a short time).

Fig. 4.b presents the same results, this time with collaborative control ($K_h = K_r = 0.5$). In this case, we do not only represent the ratio between robot and human but also between shared control and human. It can be easily observed that shared control is closer to human performance but, yet, better. It is especially interesting to note that there are fewer peaks in this second case. It is important to note that the axes of the graphs are at different scales, especially in the last case, for the sake of visibility. This means that the differences between the global shared efficiency and the human one (second graph) are clearly lower in Fig. 4.b than those between the robot and the human (first graph), meaning that the user is expected to feel more in control when shared control is performed.

Fig. 5.a presents a decomposition of the global efficiency of the system -for PFA, human control and emergent shared performance) into the three different local efficiencies described

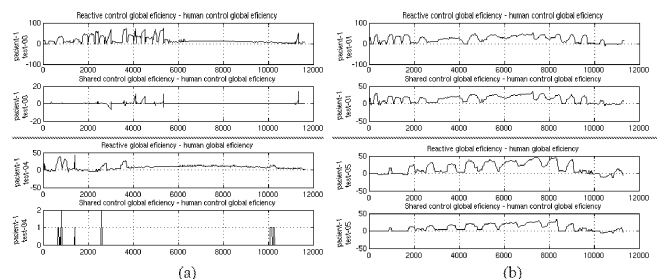


Fig. 4. Efficiencies following a straight line for: a) human control; and b) shared control

in Eq. 2. The resulting emergent trajectory is presented in Fig. 5.b. It can be observed that there is a local minimum in the reactive control efficiency, both for directiveness and smoothness, when PFA try to cross the door on their own, even though this patient has not so much trouble in doing so. As a result, their combined output performs worse than human alone but better than PFA on their own (door crossing is reported as a typical problem for PFA and this problem could be easily solved by replacing them by any other reactive algorithm). However, as soon as the patient is out of the room and needs to turn, PFA performs clearly better. Initially, both human and PFA have a local minimum in their efficiencies in terms of smoothness, as they need to turn to head the corridor. However, after this turn PFA perform basically well -despite minor oscillations due to wall closeness-, whereas the user (this example has been purposefully chosen to show this effect) has trouble heading in the correct direction (parallel to the wall). It can be observed that the user's efficiencies drop down drastically for a while. This is obvious as well in the resulting trajectory (Fig. 5.b), where the commands of the user are reflected, although softened by the PFA, in the oscillations in the path. It is interesting to note, though, that the shared efficiencies (Fig.5.a) are considerably higher than the user's ones, even though the wheelchair still obeys his commands.

Fig. 6 presents an alternative representation to check the three local efficiencies, as well as the global one: each becomes the R, G and B channel of the RGB colour space. If all efficiencies are high, the colour of a given point of the trajectory is high and white. Pure colours correspond to two low factors and combined colours to a decrease in a single factor. It can be observed that reactive control is not good for door crossing (Fig. 6.a), as potential fields are reported to present oscillations under these circumstances. Nevertheless, it recovers soon. The user does not perform so well, especially when she needs to turn right to position herself in the corridor. Until the end of the trajectory, softness is not recovered. However, she was better than the robot to go through the door, as she was careful with respect to distance and moved in a straight way. In this case, the full potential of shared control can be observed in Fig. 6.c, as it clearly improves performance not only the user's but also the one of the robot and equalizes them.

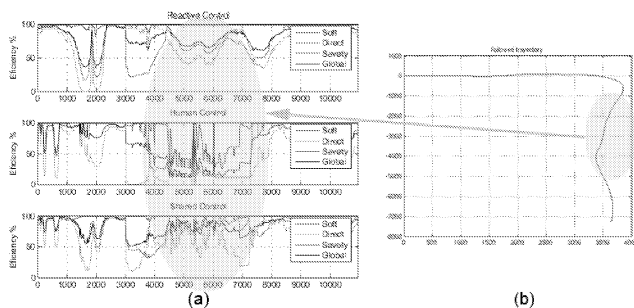


Fig. 5. Efficiencies following a straight line for: a) human control; and b) shared control

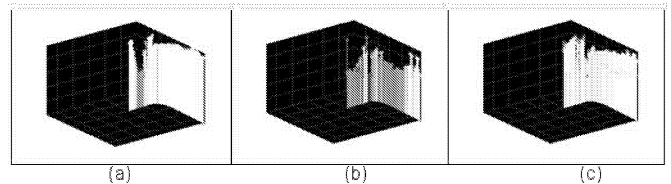


Fig. 6. Efficiencies following a straight line for: a) human control; and b) shared control

Fig.7 presents trajectories for 18 different patients coming from the corridor to enter the door. The door position has been over imposed to the graph for better visualization. It can be noted that most trajectories are basically the same except at the turning point, where there are some variations depending on how soon the patient starts to steer. It can be observed that all of them were capable of crossing the door. Two conclusions can be extracted from this figure: i) shared control tends to homogenize the performance of the users despite their conditions; and ii) the user retains control to adapt trajectories to his/her commands.

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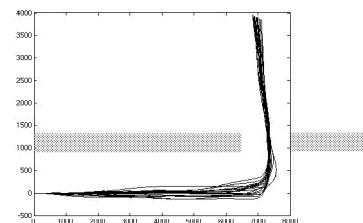


Fig. 7. Door crossing trajectories for 18 different patients