Cogn Process (2009) 10 (Suppl 2):S215–S218
DOI 10.1007/s10339-009-0274-y

EXTENDED ABSTRACT

A study on a shared control navigation system: human/robot collaboration for assisting people in mobility

Francesco Galluppi · Cristina Urdiales · Isabel Sanchez-Tato · Francisco Sandoval · Marta Olivetti Belardinelli

Introduction

Ageing of the population is a well-established global trend, especially in developed countries (United Nations 2007). As population gets older, the need for an efficient medical care system, capable of providing long-term assistance, becomes a central concern, especially with regard to the ability of older people to live independently in the community (Guralnik et al. 1996). One of the most important factors considered in measuring the quality of life for elderly is mobility (Metz 2000), and mobility devices are the most used (LaPlante 1993) and abandoned ones (Phillips and Zhao 1993). Reduced mobility plays a big role in independence and autonomy loss and could result in hospitalisation, with its related lowering of personal conditions and augmenting institutional costs (Schultz 1992).

Robotics could be used to help people with mobility, by implementing an autonomous robot in ATs, such as wheelchairs. In fact, there are many systems that take care of the navigation task taking the user where he wants to, without interacting with him after the goal has been set (Gomi et al. 1998). Other systems automatically override the user when a danger is detected or switch to autonomous navigation if the user decides so (Morris et al. 2003).

However, the goal of an AT is to assist the human in a task, not to replace him, since this might lead to frustration and loss of residual abilities whenever the AT takes over the control of the device.

In this study, a shared control navigation system is examined (Urdiales et al. 2009), where a pure reactive robotic layer assists the user in navigating a wheelchair, constantly collaborating with him and supplying the help needed. This approach relies on the idea that the robot and the human should cooperate in order to enhance the navigation task performance, both from an efficiency and user satisfaction point of view (Galluppi et al. 2008).

Implementation of the shared control is described in the "Methods" section, along with the description of the experiments carried on a Meyra power wheelchair (although this system could easily be extended to any navigation device), used by volunteers, at the hospital "Fondazione Santa Lucia",[1] in Rome. Results are outlined in the "Results" section. Finally some key-points are summarised in the "Conclusions".

Methods

A shared control navigation approach has been used (Urdiales et al. 2007), where human and robot constantly share influence on the final behaviour of the AT, by providing

F. Galluppi (✉) · M. O. Belardinelli
Department of Psychology, "Sapienza" Università di Roma, Rome, Italy
e-mail: francesco.galluppi@gmail.com

M. O. Belardinelli
e-mail: marta.olivetti@uniroma1.it

C. Urdiales · F. Sandoval
E.T.S.I. Telecomunicacion, Universidad de Málaga, Malaga, Spain
e-mail: cristina@dte.uma.es

I. Sanchez-Tato
Centro Andaluz de Innovación y Tecnologías de la Información y las Comunicaciones, Malaga, Spain

M. O. Belardinelli
ECONA – Interuniversity Centre for Research on Cognitive Processing in Natural and Artificial Systems, Rome, Italy

[1] http://www.hsantalucia.it.

an input which is consequently weighted by efficiency factors and linearly combined into a shared output trajectory.

The user provides the input direction via the wheelchair's joystick, while the robot calculates the trajectory using a potential field approach (PFA) (Khatib 1986). PFA couples sensors reading and output commands by modelling the goal point as an attractor and obstacles as repulsors, thus creating a vector space, where the output vector is calculated.

The direction provided by the robot is then combined with the one provided by the user, weighting them by local efficiency at every time instant. So the output trajectory U will be

$$\vec{U} = \eta_h \cdot \vec{I}_h + \eta_r \cdot \vec{I}_r \quad (1)$$

where $I_h \cdot \eta_h$ and $I_r \cdot \eta_r$ are the input vectors and local efficiencies of human and robot, respectively. Efficiency is the weight used to mix the trajectories proposed by the user and by the robot in order to achieve a shared direction which is the most efficient and safer one, while the user is constantly in control of the navigation. If the user is performing well, his efficiency will increase, and so will his influence on the final behaviour of the device. On the contrary, if user's performance degrades, his efficiency will be lowered and the robotic reactive layer will increment its influence, providing help as needed.

Efficiency is calculated as the weighted sum of three factors: *smoothness*, *directivness* and *security*. Smoothness avoids abrupt oscillation in the trajectory, by locally evaluating the angle difference α_{diff} of the proposed heading and the current heading. Smoothness efficiency is expressed as $\eta_{sm} = e^{-C1|\alpha\mathrm{diff}|}$, therefore the softer the trajectory is, the more efficient. Directivness efficiency is expressed as $\eta_d = e^{-C2|\alpha\mathrm{dest}-\alpha\mathrm{diff}|}$ and evaluates the difference angle α_{dest} between the destination point and the proposed one; the more the trajectory keeps the goal ahead, the more efficient it is. Security avoids getting too close to obstacles, thus providing a safer navigation. It is expressed as $\eta_{sec} = 1 - e^{-C3|\alpha\min-\alpha\mathrm{diff}|}$, where $\alpha_{\min}$ is the angle difference to the closest obstacle.

Thus efficiency is the combination of the three factors:

$$\eta = \frac{\eta_{sm} + \eta_d + \eta_{sec}}{3}. \quad (2)$$

Factors and global efficiency are calculated for the user and the robot separately and then linearly mixed in an output shared trajectory, according to (1).

The algorithm described has been implemented on a wheelchair controlled via a joystick, and has been tested on 27 volunteering patients, presenting different cognitive or physical disabilities (Urdiales et al. 2009). Volunteers were asked to navigate from a corridor to a room and vice versa, crossing a 90-cm door. Subjects repeated each trial twice.

Results

At every time instant, separated efficiencies of human, reactive, and shared control were collected, along with the position of both chair and obstacles. Efficiencies were then confronted, evaluating their mean and variance along the trajectory. Results are presented in Table 1. Global efficiency is best in the reactive control, compared to the shared control which is a little lower; the human control is by far the worst. It is also interesting to notice that shared control lowers the variation in efficiency among different users, leading to a more homogeneous performance. Therefore, globally shared control significantly improves human performance, making it more similar to robot's, and reduces differences in efficiency between different users. Efficiency was then measured for the three distinct factors separately. Regarding *softness*, shared control is significantly better than human and robot—and it has less variation, managing to mix the most efficient part of human's and robot's inputs in a smoother trajectory. As for *directivness* robot's efficiency is better, while human is by far the worst; shared control manages to compensate human performance and once again presents less variation among different users. Finally, with respect to *security*, shared control is the best and the one with less variation among users. Analysis has been replicated separately for the two trials (entering and exiting the room) with similar results, as reported in Fig. 1.

Conclusions

Shared control attains an improved efficiency in navigation, cooperating with the user and the robot constantly mixing the most efficient part of the interacting trajectories proposed. It also reduces differences among users presenting different physical and cognitive impairments, by increasing the efficiency and lowering the variance.

Table 1 Efficiency mean/standard error results from trials

	Reactive	Joystick	Shared
Mean			
Softness	72.99	68.48	81.35
Directivity	77.02	40.17	59.64
Security	96.61	93.14	98.05
Global	82.19	67.19	79.7
Standard error			
Softness	7.95	15.05	5.38
Directivity	8.19	15.47	10.60
Security	3.10	7.09	1.16
Global	5.73	11.62	4.98

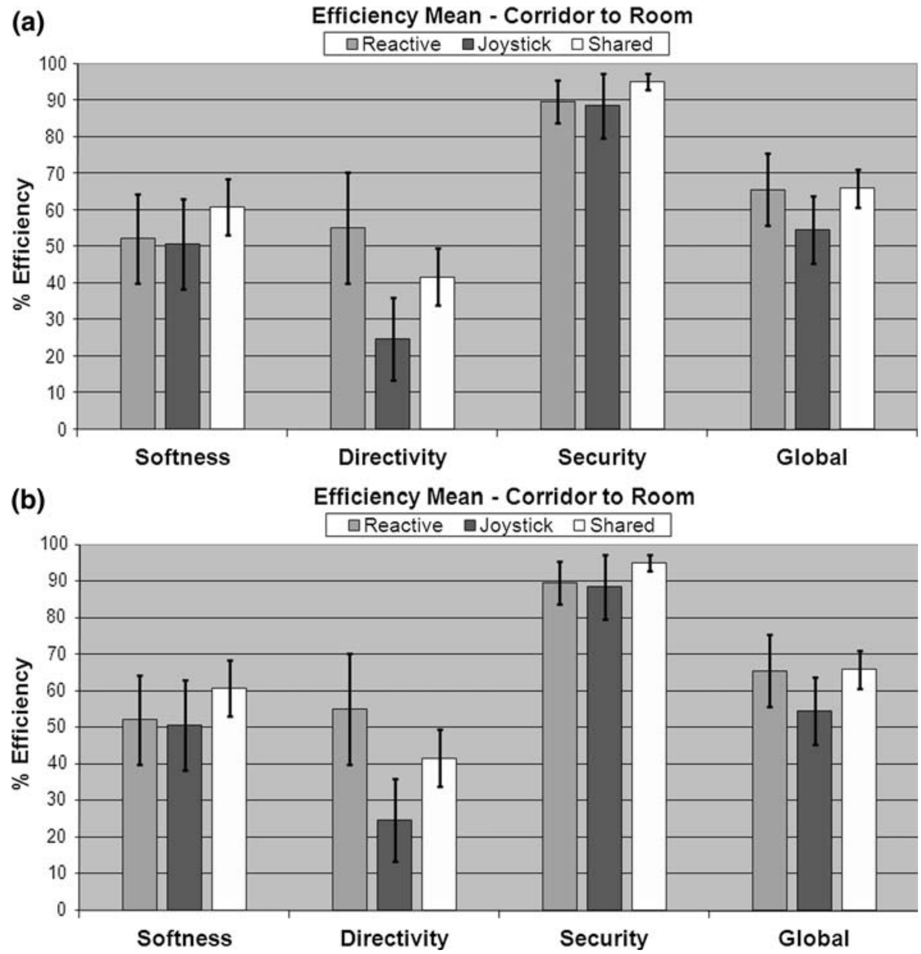

Fig. 1 Distinct efficiency mean for the two trials. *Black bars* denote standard deviation. **a** room to corridor navigation, **b** corridor to room navigation

The main advantage is the feeling of control that the user gets when using the AT. Furthermore, the better the user performs the more control he gains over the device. Among the personal factors accounting for use and abandonment of ATs, perceived self-efficacy and personal control are very important (Fuhrer et al. 2003). Self-efficacy in particular has proven to be of importance towards ATs' use (Gecas 1989) and rehabilitation (Ristner 2000). The loss of control could cause loss in self-efficacy (Mann et al. 1999) and lack of stimulus in a rehabilitation process. Another important feature of the shared control is its ability to provide the amount of help needed, adapted to user's needs and changing conditions (Scherer and Galvin 1996), indeed, durability is key in ATs' abandonment (King 1998).

Acknowledgments This work has been partially supported by the Spanish Ministerio de Educación y Ciencia (MEC) and FEDER funds, project No. TEC2006-11689-C01/TCM and also by EU STREP project SHARE-IT IST-045088. All experiments have been previously authorised by the FSL ethical committee. The authors would like to thank FSL and all volunteers for their kind cooperation and Sauer Medica S.L. for providing the power wheelchair.

References

Fuhrer MJ, Jutai JW, Scherer MJ, DeRuyter F (2003) A framework for the conceptual modelling of assistive technology device outcomes. Disabil Rehabil 25(22):1243–1251

Galluppi F, Urdiales C, Poncela A, Sanchez-Tato I, Sandoval F, Olivetti Belardinelli M (2008) A study on human performance in a cooperative local navigation robotic system. 2008 Workshops on enabling technologies: infrastructure for collaborative enterprises, pp 48–53

Gecas V (1989) The social psychology of self-efficacy. Annu Rev Sociol 15:291–316

Gomi T, Grifth A (1998) Developing intelligent wheelchairs for the handicapped, Springer, Berlin, pp 150–178

Guralnik JM, Fried LP, Salive ME (1996) Disability as a public health outcome in the aging population. Annu Rev Public Health 17:25–46

Khatib O (1986) Real-time obstacle avoidance for manipulators and mobile robots. Int J Robot Res 5(1):90–98

King TW (1998) Assistive technology; essential human factors. Allyn and Bacon, Boston

LaPlante MP (1993) Prevalence of mobility and self-care disability-United States, 1990. Morbid Mortal Wkly Rep 42:760–768

Mann WC, Ottenbacher KJ, Fraas L, Tomita M, Granger CV (1999) Effectiveness of assistive technology and environmental interventions in maintaining independence and reducing home care costs for the frail elderly. Arch Fam Med 8:210–217

Metz D (2000) Mobility of older people and their quality of life. Trans Policy 7(2):149–152

Morris A, Donamukkala R, Kapuria A, Steinfeld A, Matthews J, Dunbar-Jacobs J, Thrun S (2003) A robotic walker that provides guidance. In: Proceedings of the IEEE International Conference on Robotics and Automation—ICRA2003

Phillips B, Zhao H (1993) Predictors of assistive technology abandonment. Assist Technol 5:36–45

Ristner G (2000) Sense of coherence and lack of control in relation to outcome after orthopaedic injuries. Injury 31(10):751–756

Scherer MJ, Galvin JC (1996) An outcomes perspective of quality pathways to most appropriate technology. In: Galvin JC, Scherer MJ (eds) Evaluating, selecting and using appropriate assistive technology. Aspen Publishers, Inc., Gaithersburg, pp 1–26

Schultz AB (1992) Mobility impairment in the elderly: challenges for biomechanics research. J Biomech 25(5):519–528

United Nations (2007) World population prospects: the 2006 revision. New York, United Nations. (http://www.un.org/esa/population/publications/wpp2006/wpp2006_ageing.pdf)

Urdiales C, Poncela A, Sanchez-Tato I, Galluppi F, Olivetti Belardinelli M, Sandoval F (2007) Efficiency based reactive shared control for collaborative human/robot navigation. Intelligent Robots and Systems IROS2007, 3586–3591

Urdiales C, Peula JM, Barrue C, Pérez EJ, Sánchez-Tato I, del Toro JC, Galluppi F, Cortés U, Annichiaricco R, Caltagirone C, Sandoval F (2009) A new collaborative shared control strategy for continuous human/robot assisted navigation. Submitted to Autonomous Robots