The CyberWalk Platform: Human-Machine Interaction Enabling Unconstrained Walking through VR

P. Robuffo Giordano, J. L. Souman, R. Mattone, A. De Luca, M. O. Ernst and H. H. Bülthoff

SUMMARY

In recent years, Virtual Reality (VR) has become increasingly realistic and immersive. Both the visual and auditory rendering of virtual environments have been improved significantly, thanks to developments in both hardware and software. In contrast, the possibilities for physical navigation through virtual environments (VE) are still relatively rudimentary. Most commonly, users can 'move' through high-fidelity virtual environments using a mouse or a joystick. Of course, the most natural way to navigate through VR would be to walk. For small scale virtual environments one can simply walk within a confined space. The VE can be presented by a cave-like projection system, or by means of a head-mounted display combined with head-tracking. For larger VEs, however, this quickly becomes impractical or even impossible.

Different locomotion interfaces already exist that allow walking in virtual environments (see, e.g., the surveys in [1] and [2]). However, they usually constrain the feet, the body, or the legs of the user. Moreover, locomotion is either restricted to a 1D motion on a linear treadmill, like in the Treadport platform [3] with possible slope effects [4], or is limited in space and speed, like in the case of the moving tiles of the CirculaFloor [5]. In the *CyberWalk* European research project [6], we set out to develop an omnidirectional treadmill system that allows for unconstrained walking in all directions through large scale virtual environments. To this end, a novel motion concept for unconstrained walking on a plane has been developed: the "omni-directional" *CyberWalk* platform (Figs. 1–2). The platform consists of an array of synchronous linear belts $C_1, C_2, \ldots, C_N$ that can be displaced with a common velocity v_{cx} in the (blue) direction, which is orthogonal to the (yellow) velocity v_{cy} of each independent belt. Thus, a velocity with any (green) direction in the plane can be obtained as a combination of the two linear motions. This concept is similar, although with different implementations of the mechanical, actuation, and control parts, to the Omnidirectional Treadmill proposed in [7], which uses two perpendicular belts and a large number of rollers, and to the Torus Treadmill [8], having a torus-shaped belt arrangement but of quite small dimensions.

On the *CyberWalk* platform, the walker can experience slow or fast locomotion in any planar (possibly infinite) direction, or even step over and cross her/his legs, while remaining on the platform. Walker's position is regulated by a platform controller that counteracts the walker's voluntary motion and pulls her/him toward the center of the platform, taking into account physiologically acceptable velocity/accelerations bounds. The body pose on the platform is acquired through a Vicon motion capture system and is used both to estimate the walker voluntary motion (through suitably designed observers), and to drive the actuation devices that move the platform in the two directions. The combined walker-platform displacement is also needed to update the scene of the virtual environment shown to the user through a head mounted display (Fig. 3). The overall control system architecture of the *CyberWalk* platform is illustrated in Fig. 4.

A full-scale prototype of this omni-directional platform (with a side of 5 m, see Fig. 2, it is one of the largest VR platforms in the world) has been built by the Technical University of Munich within our European project, and is currently located by the other project partner in Germany, the Max Planck Institute of Tübingen (Fig. 5). The overall

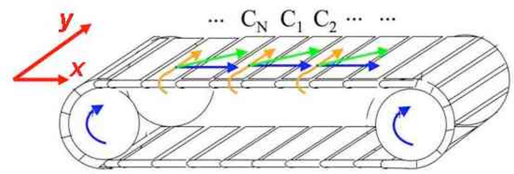

Fig. 1: The kinematic concept of the 2D *CyberWalk* platform (German Patent filed in 2006 by TUM, Munich)

Fig. 2: The realized 2D *CyberWalk* platform (picture courtesy of TUM, Munich)

P. Robuffo Giordano, J. L. Souman, M. O. Ernst, and H. H. Bülthoff are with the Max Planck Institute for Biological Cybernetics, Spemannstraße 44, 72076 Tübingen, Germany.

R. Mattone and A. De Luca are with the Dipartimento di Informatica e Sistemistica, Università di Roma "La Sapienza", Via Ariosto 25, 00185 Roma, Italy.

Fig. 3: A snapshot of virtual Pompeii, the VE shown to the user (picture courtesy of ETH, Zurich)

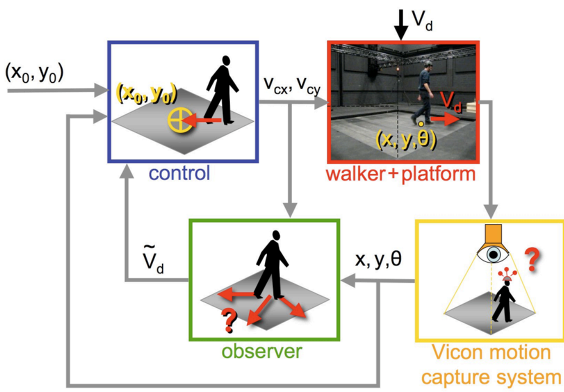

Fig. 4: Control system architecture of the *CyberWalk*

system was also successfully presented to the scientific community and to the press during the *CyberWalk* workshop[1] organized by the Max Planck Institute on April 17–18th, 2008.

In this talk, we will illustrate the various components of the *CyberWalk* system, with a particular emphasis on the design, implementation and experimental evaluation of the platform controller developed by the University of Roma "La Sapienza" [9], [10], [11], [12]. Indeed, besides being able to compensate for the unknown walker's motion, the feedback law must also cope with specific perceptual constraints arising from the close interaction between platform and user. For instance, acceleration of the platform cannot be too high, because this would disrupt the immersiveness of the virtual reality or even bring the user out of balance. On the other hand, it cannot be too low either, because then the person would soon walk out of the treadmill when he or she abruptly changes walking speed. In other words, a safe and dependable human-machine interaction must be enforced in order to meet all the perceptual requirements of the *CyberWalk* project: the control law must keep the walker near to the platform center and must not violate physiological constraints, such as comfortable accelerations and jerks [13]. To this end, we have proposed a second-order (acceleration) feedback coupled with a feed-forward term function of the online estimation of the walker's voluntary acceleration and velocity. Together with a suitable gain scheduling based on the walker's heading direction, this design proved to be effective in regulating the walker's position while also satisfying the perceptual constraints of immersiveness in the VE.

[1] `http://cyberwalk.kyb.tuebingen.mpg.de`

Fig. 5: The final *CyberWalk* platform located at the Max Planck Institute of Tübingen

ACKNOWLEDGEMENTS

Work supported by the EU project FP6-511092 *CyberWalk*. We also acknowledge the Max Planck Society for its support.

REFERENCES

[1] H. Iwata, "Locomotion interface for virtual environments," in *Proc. 9th Int. Symp. on Robotics Research*, 2000, pp. 275–282.

[2] J. M. Hollerbach, "Locomotion interfaces," in *Handbook of Virtual Environments Technology*, K. M. Stanney, Ed., 2002, pp. 239–254.

[3] J. M. Hollerbach, Y. Xu, R. R. Christensen, and S. C. Jacobsen, "Design specifications for the second generation Sarcos Treadport locomotion interface," in *Haptic Symposium, Proc. of ASME Dynamic Systems and Control Division*, 2000, pp. 1293–1298.

[4] R. C. Hayward and J. M. Hollerbach, "Implementing virtual stairs on treadmills using torso force feedback," in *Proc. 2002 IEEE Int. Conf. on Robotics and Automation*, Washington, DC, 2002, pp. 586–591.

[5] H. Iwata, H. Yano, H. Fukushima, and H. Noma, "CirculaFloor," *IEEE Computer Graphics and Applications*, vol. 25, pp. 64–67, 2005.

[6] *CyberWalk*, "EU STREP Project FP6–511092, http://www.cyberwalk-project.org," 2005.

[7] R. Darken, W. Cockayne, and D. Carmein, "The Omnidirectional Treadmill: A locomotion device for virtual worlds," in *Proc. Symp. User Interface Software and Technology*, 1997, pp. 213–221.

[8] H. Iwata, "The Torus Treadmill: Realizing locomotion in VEs," *IEEE Computer Graphics and Applications*, vol. 9, pp. 30–35, 1999.

[9] A. De Luca, R. Mattone, and P. Robuffo Giordano, "The motion control problem for the CyberCarpet," in *Proc. 2006 IEEE Int. Conf. on Robotics and Automation*, Orlando, FL, 2006.

[10] ——, "Feedback/feedforward schemes for motion control of the CyberCarpet," in *Proc. 2006 IEEE Symp. on Robot Control*, Bologna, I, 2006.

[11] ——, "Acceleration-level control of the CyberCarpet," in *Proc. 2007 IEEE Int. Conf. on Robotics and Automation*, Rome, I, 2007, pp. 2330–2335.

[12] ——, "Control design and experimental evaluation of the 2D Cyber-Walk platform," *submitted to the 2009 IEEE Int. Conf. on Robotics and Automation*, 2009.

[13] J. L. Souman, P. Robuffo Giordano, I. Frissen, A. De Luca, and M. O. Ernst, "Making virtual walking real: perceptual evaluation of a new treadmill control algorithm," *submitted to the ACM Trans. on Applied Perception*, 2008.