Wearable Locomotion Interface using Walk-in-Place in Real Space (WARP) for Distributed Multi-user Walk-through Application

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Abstract

A wearable locomotion interface device using walk-in-place in real space (WARP) was developed. The hardware of WARP consists of two hip joint angle sensors, a geomagnetic sensor for body orientation detection, a one-chip microprocessor and a serial communication chip. A real-time velocity estimation algorithm was proposed to allow the delay-free velocity control and to reflect the stepping stride amplitude as well as frequency. The proposed algorithm attained the delay-free velocity control at any phase of the walking. The velocity estimation performance of WARP was also demonstrated through a treadmill experiment. A virtual space walking direction control using body orientation in real space showed good performance in a walk-through experiment.

1. Introduction

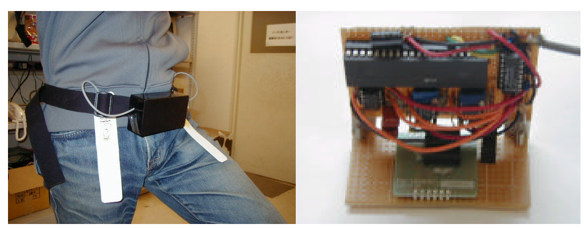
Numbers of locomotion interface devices have been developed to attain natural locomotion in cyber-space. Treadmill-based locomotion interface devices allowed users to walk by driving the belt to counteract the user's motion. Some improved treadmill-based systems attained free-directional walking. The principal disadvantages are size, cost and restriction of the user vision around the feet in the case of the projection type immersive display.

Several types of locomotion interface devices using gesture motion, such as hand motion, body position and walking-in-place, are also proposed. However Walking-in-place is an intuitive motion to control the movement in virtual space, several difficulties have been remained. The most serious problem is the delay of the velocity estimation that is unavoidable in stepping cycle detection. It is a potential cause of cyber-sickness. The easily wearable and less costly hardware has also been required especially for the distributed multi-user walk-through application.

In this study, a small-packaged wearable locomotion interface device using walking-in-place in real space (WARP) that has real-time velocity estimation algorithm is proposed.

2. Hardware of WARP

Because the changing pattern of the difference of two hip joint angles is sinusoidal during walking and walking-in-place, WARP utilized two bend sensors to detect the hip joint angles. Two strain gauges were glued to each poly-vinyl chloride plate. The upper side of the plate was fixed to a buckle as shown in figure 1(a). The output signals from a TOKIN TMS3000NF geomagnetic sensor to estimate the body orientation angle and the amplified strain gauge signals are analog-to-digital converted by a Microchip PIC16F877 microprocessor. The A/D converted signals are transmitted to a host PC through RS232C serial communication line.



(a) (b)

Figure 1. (a) A user wearing WARP. (b) Inside circuit of WARP.

3. Real-time velocity estimation algorithm

The difference of hip angles has a sinusoidal pattern during stepping motion as well as walking. The walking speed was calculated as follows by assuming the hip joint difference angle $q = a \cos wt$.

Because the leg length ℓ is constant, the stride length is proportional to the amplitude a. Similarly, the walking speed is proportional to the stepping frequency w. Therefore, the walking speed is given as

$$v = \ell / p \sqrt{\left(\frac{dq}{dt}\right)^2 + q^2 \frac{dq}{dt}} \Big/ \int q dt \qquad (1)$$

Because this algorithm uses only the instant values, it is possible to stop at any phase of the stepping motion without delay. The serial communication and velocity estimation function was programmed as a task-tray program to allow the independent application program development from WARP control.

4. Direction control algorithm

To allow free-directional walking in a single screen environment, it is necessary to rotate the walking direction in virtual space with some algorithm. Use of the body orientation relative to the screen is the most intuitive method. In this study, we propose the following algorithm.

Define the body orientation angle relative to the screen in real space, the viewing direction in virtual space and the walking direction in virtual space as q, a, b. The viewing and walking direction at time k is calculated as follows;

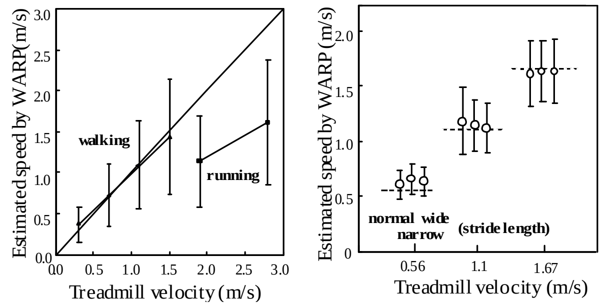
$$\begin{cases} a_k = a_{k-1} + K(q_k - q_{th})\Delta t & (q_k \geq q_{th}) \\ a_k = a_{k-1} & (q_k < q_{th}) \\ b_k = a_k + q_k & \end{cases} \qquad (2)$$

By using this algorithm, the user is able to walk to the facing direction while the body orientation angle is within the threshold angle q_{th} (insensitive zone). The walking direction starts to rotate with the angular velocity proportional to the body angle when the body orientation angle exceeds the threshold.

5. Performance evaluation

The velocity estimation accuracy was evaluated by using at motor-driven treadmill. As shown in figure 2, WARP demonstrated accurate walking velocity estimation performance during walking. The change of the stride length and the frequency did not affect the estimated velocity. It is concluded WARP provides the accurate and robust walking velocity estimation.

The direction control performance was also evaluated in 60m zigzag walking (ski slalom like task) in virtual space with 2 or 5 meters turning interval. As shown in figure 3, the insensitive zone provided the higher and almost the same as the straight walking speed. The stable straight walking and direction controllability was attained.



(a) (b)

Figure 2. Relationship between the treadmill velocity and the estimated velocity by WARP. (a) normal walking and running. (b) various stride walking.

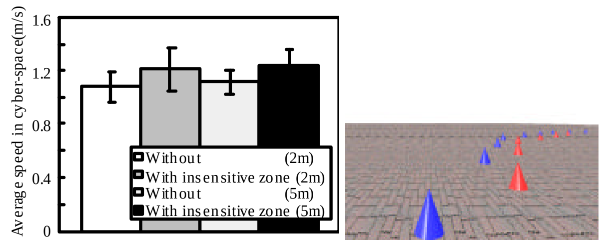


Figure 3. Direction control performance with / without insensitive zone in virtual space zigzag walking

6. Conclusion

A wearable locomotion interface device using walk-in-place in real space (WARP) that enables delay-free velocity control and environment-free direction control was developed. A free walking distributed multi-user communication system using WARP has also been developed and successfully utilized.

This work was partially supported by the program "The R&D support scheme for funding selected IT proposals" of the Ministry of Public Management, Home Affairs, Posts and Telecommunications.

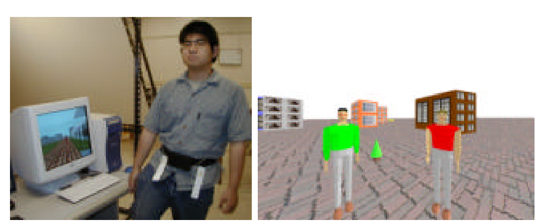


Figure 4. A scene of distributed multi-user walk-through using WARP.