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A Seated Robotic Interface to Control Walking of Physical and Virtual Avatars

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I. INTRODUCTION

Walk-in-place locomotion control interfaces allow users to control walking of remote human-like robotic systems or virtual reality avatars [2]. This extended abstract overviews an ankle robotic interface that is designed recently to control the walking of virtual or physical/robotic avatars. The interface allows a seated user to perform walking control through feet tapping gestures and feel the remote/virtual terrain through haptic feedback. There were multiple seated walking-in-place interfaces developed previously [1], [8], [9] but our interface has multiple combined advantages, such as use of simple single-degree-of-freedom actuated platform, seated and hands-free ergonomics, and ability to simultaneously provide haptic feedback. These functionalities are briefly outlined in the following sections. The video demonstration of the system is available at https://www.youtube.com/watch?v=wPvGWuyjBl4.

II. ANKLE INTERFACE FOR WALKING CONTROL

The designed seated walk-in-place interface and its functional operation diagram are shown in Fig. 1. The hardware components include a single capstan driven 1-DOF foot platform, a backdrivable brushed DC motor, control electronics, a height adjustable chair and a commercial VR headset (Oculus Rift CV1). The users are expected to sit on the chair, place their feet on the platform and perform ankle dorsiflexion and plantarflexion movements while keeping their heels stationary. The seat location is adjusted to fit the body size of the user by sliding the chair along the connection to the platform and using the height adjustment of the chair. A geared back-driveable DC motor actuates the platform through capstan transmission. Platform angle and angular velocity, which are essential to detecting the feet movement, are measured using the optical shaft encoder connected to the DC motor. A proportional-derivative (PD) controller along with gravity compensation is used to control the platform's angular orientation. Our earlier publication [3], [5], [6], focused on the design and control of the platform, can provide more insight on its mechanical properties.

III. WALKING CONTROL ALGORITHM

Users are required to make stepping gestures comprising consequent left/right ankle plantar/dorsiflexion movements to achieve walking in the VR scene. Such repetitive stepping gestures correspond to physical ankle movements during natural walking. The periodic left/right ankle flexion gestures can be efficiently realized with a single actuated robotic platform. For efficient locomotion while continuously stepping, a smooth transition between right and left foot movement is required similar to how natural walking requires a smooth load transfer between legs. Using a single platform enforces a rhythmic feet movement.

The platform's angular orientation is used to calculate the forward movement of the avatar. Our algorithm aims to compute the exact phase of the stepping movement so that any VR avatar with a suitable walking animation can be utilized. By matching the users gesture movement to the walking cycle of the anthropomorphic avatar, we aim to improve the sense of embodiment the user feels. The algorithm divides the platform angle data, θ and its derivatives to divide the stepping motion into six regions as listed below and depicted in Fig. 2.

- stopping regions: $|\dot{\theta}| < \omega_0$
    1) when foot is lifted: $\dot{\theta} > 0$ in the previous region.
    2) when foot is pressed: $\dot{\theta} < 0$ in the previous region.
- movement regions: $|\dot{\theta}| > k\omega_0$, where $n > 1$
    3) accelerating upwards: $\dot{\theta} > 0$, $\ddot{\theta} > 0$
    4) decelerating upwards: $\dot{\theta} > 0$, $\ddot{\theta} < 0$
    5) accelerating downwards $\dot{\theta} < 0$, $\ddot{\theta} < 0$
    6) decelerating downwards $\dot{\theta} < 0$, $\ddot{\theta} > 0$

The algorithm detects every time a transition from one region to another occurs. The aim of the algorithm is to estimate the step phase between the transition events, presented by dotted lines in Fig. 2, and correct for the error as the transition events occur. A step phase variable is introduced to compute the gait phase for the avatar's legs' motion based on the identified phase transitions.

IV. HAPTIC TERRAIN FEEDBACK

The purpose behind designing the interface as an actively controlled platform, rather than one that has fixed compliance, is to be able to alternate the impedance depending on the VR terrain. We believe that terrain information is crucial in helping the users understand their self-motion and supporting their visual sense of motion. Our platform is capable of rendering various types of programmable haptic feedback to mimic walking on different virtual surfaces or provide realtime haptic feedback from the tactile sensors of a remotely operated robotic avatar. For example, the system can render walking on

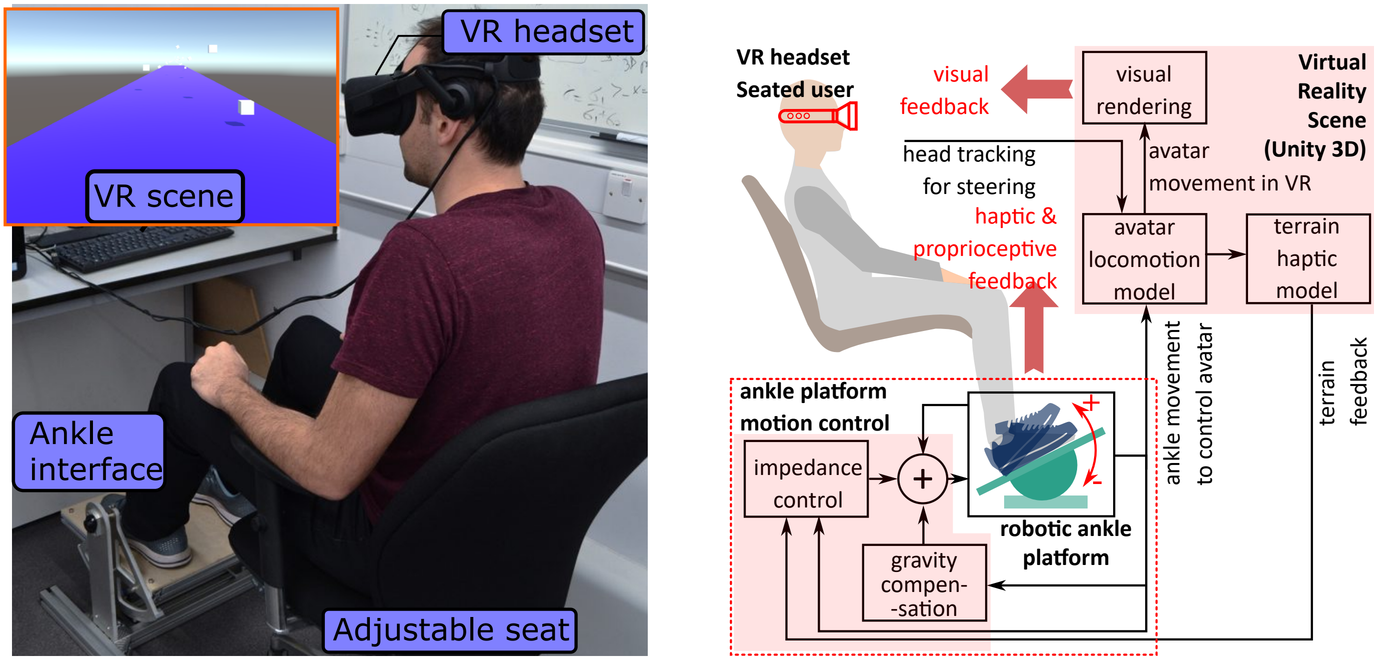

Fig. 1: **Left:** Ankle motion-based walking interface for seated VR. **Right:** Block diagram of the motor controller program and the Unity program showing how the physical platform and VR avatar are controlled. Information related to desired avatar speed in VR is transmitted from the motor controller to Unity. Upon making necessary updates on the location of the VR avatar, corresponding terrain type is transmitted to the motor controller to update related parameters in the impedance controller.

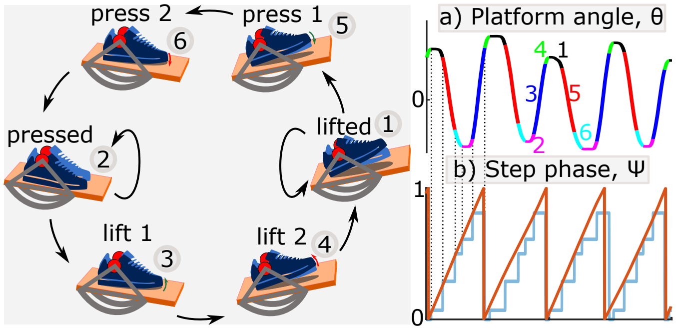

Fig. 2: **Left:** stages of movement for a single foot with region numbers written in gray circles. **Right:** a sample platform angle to step phase mapping using the presented algorithm.

rigid surfaces (concrete), soft materials (carpets) or even more complex dynamic structures (ice, snow).

V. EXPERIMENTAL EVALUATION

Performance of the designed seated walking control platform was tested with virtual human-like robotic avatar. The avatar movement commands produced by the walking algorithm were communicated to a Unity 3D application where the avatar was animated accordingly. A desktop computer is used to communicate between the data acquisition device and the virtual reality scene. The VR headset provides the user visual feedback and provides the Unity application user's head orientation, which is used for avatar steering.

Three experimental studies were conducted with human-participants: learning walking control gestures [4]; haptic perception of virtual walking terrains [4]; and walking speed control [7].

In the learning walking gestures experiment [4] the participants (N=11) were able to master ankle platform operation and control walking of a remote avatar within 10 trials ($<$ 10 mins). They were able to re-tain their skill in test trials that were run 7 days after the introductory trials.

In speed control experiments [7] the participants (N=8) used the proposed ankle walk-in-place interface to control the speed of walking of a virtual avatar. In the experiments the users were asked to follow a second (lead) avatar that walked at a variable unknown speed. The experiment demonstrated that all participants were able to adjust the speed of walking to maintain the required distance to the lead avatar.

In haptic terrain perception experiments [4] three types of the virtual terrains were used for walking environment: hard concrete, soft carpet and crunchy ice-snow terrain models. With the help of haptic terrain rendering capability of the proposed interface the participants (N=9) were able to discriminate efficiently between different terrain types. The highest identification rate was recorded for stiff terrain (88%). Soft and crunchy terrains had correct response rates of 75% and 70%, respectively.

In the future, we plan to integrate the designed interface with teleoperation of legged robots to demonstrate the benefits of user-robot lower limb embodiment on remote locomotion and navigation in unstructured and extreme environments.

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