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An Omnidirectional System for Navigation in Virtual Environments

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Abstract. Virtual Reality (VR) is one of the newest technological domains with revolutionary applicability for the tomorrow's Future Internet, including visions of the Internet of Things. The sensation of total immersion in Virtual Environment (VE) is still unresolved. Therefore, our work proposes a new omnidirectional locomotion interface for navigation in VEs. The novel interface was built from an ordinary unidirectional treadmill, a new mechanical device, a motion capturing system to track the human walking and a control method using artificial intelligence techniques. A neural network is used to predict the motion of the new interface based on user's body motion and information about VE. The feasibility of the proposed system is verified through experiments and the preliminary results suggest that the new interface performs very well in a simplest VE based on our control method.

Keywords: Virtual Reality, navigation, Virtual Environment, locomotion interface, neural network

1 Introduction

Nowadays, Virtual Reality (VR) has become an indispensable technology with practical applications in many areas such as medical, engineering to urban planning, training and education, sports and arts, etc. The VR is defined as the use of a computer-generated 3D environment – called a 'virtual environment' (VE). One of the hardest things to achieve in this area is to provide the immersion of the user, meaning that he can feel in a virtual world like in the real world. To achieve this, navigation is a fundamental task needed for human interaction with the VE.

In our work we deal the navigation into VE by walking because it is the main motor activity of daily life. The human gait is considered for VR field the user's most natural way of exploring a VE [4], [14]. Over the time, locomotion interfaces were built in order to not limit the navigation by walking in a VE. Due to these interfaces, the user can walk freely and his motion was compensated. Ruddle, R. A. and Lessels, S. showed that a walking interface would bring immediate benefits for navigation in virtual environments in a number of VE applications [11]. Therefore, the first research about omnidirectional (ODT) treadmill was proposed by Darken et al. [2] in 1997 and was named by the authors 'a revolutionary locomotion device that enables bipedal locomotion in *any* direction of travel'. The base principle of the ODT consists

of two perpendicular belts, one inside of the other, each of them comprised of an array of freely rotating rollers.

Another similar concept is the CyberWalk platform, one of the largest VR platforms in the world [3]. Over the years, many other locomotion interfaces have been designed and implemented. An example is ATLAS [8], that consists of a remodeled commercial treadmill and a motion platform with three axis. In the first phase the authors control the speed of the belt and further the walking direction, proposing a method than allows user to walk in any direction by cancel the turning motion of the user [7]. In [10] is used a motor-less treadmill resting on a mechanical rotating base. The belt of treadmill contains stripes along the direction of motion and measuring the angle of foot placement, the entire treadmill is rotate accordingly on a rotary base.

To achieve a target in a real environment, the human needs to walk on flat surfaces and also he need to climb or to go down surfaces with hilliness. As we could see in above researches, the currently locomotion interfaces based on ordinary treadmills are controlled by making a user navigation in VEs just on a flat surface. Therefore, in our on-going project we want to build a new locomotion interface by improving the control of an ordinary treadmill in order to allow the user to navigate also on a surface with hilliness in a VE, as in a real environment. Thus, one novelty of our on-going project is to make a complex control of treadmill to fit very well in a VR environment. Besides forward and backward navigation, it provides to the user the possibility to climb to or go down on a virtual surface with hilliness and also to turn left or right during navigation in a natural way. Our complex control of treadmill gives two main opportunities of the new locomotion interface: (i) to move in any direction in virtual worlds, and (ii) to enhance the user's immersion.

Up to the present time, controls of ordinary treadmills were done by using the classical PID controller method and derivatives of this method, such as: PD on/and PI controller [9], [12]. Although these basic controllers are most widely used, they are limited when complex processes are required to perform a task. Our locomotion interface based on an ordinary treadmill involves a complex controller because two motors need to be controlled in the same time, taking into account other two entities: user's actions and the scenarios of the VE. User's actions represent the first entity that involves the modulation through perception-action model. Thus, the user perception activity is given by treadmill motion through a natural gait. Based on 3D virtual scenario users performed the reaction activity upon treadmill.

In order to achieve the intended complex controller of the treadmill, we replaced the classical PID controller with artificial neural networks method. We have chosen to use this method because it is simplified mathematical models of brain-like systems that function as parallel, distributed computing networks [6]. Hence, artificial neural networks method let us to build a flexible cognitive control over the user's behavior and the plan of virtual scenarios.

To build the proposed complex controller of the treadmill, we had to use multiple devices, such as an ordinary treadmill (Energetics Power Run 3000 HRC), an Optitrack Motion Capturing System to track the human walking, and also we design a simplest virtual environment, as see in Fig.1 a). In addition, we had to design and build a mechanical support with two degrees of freedom (2-DOF) upon the treadmill

The outline of the paper is as follows. In section 2 is illustrated the contribution for the Internet of Things of this paper, section 3 present our prototype and the used methodologies. Experimental studies, results and a discussion are given in section 4 and finally, in section 5, is given the conclusion and the future work.

Nowadays, the speed of information technologies development is increasing more than ever. Hence, VR is one of these technologies that is often supported by the Internet of Things, by making a natural human-computer interaction for the users. One of the areas where VR found practical application is user's natural navigation by walking in 3D VEs. Thus, human locomotion inside VEs applications is an important concept that can be integrated and supported by novel technologies, promising to expand into most of today's domains and also into the concept of tomorrow's Future Internet, where Internet of Things is one of the core elements of it.

According to the definition of Internet of Things from [5]: “*Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts*”, our new locomotion interface for navigation in virtual worlds represent a promising step toward the future of the Internet. From this reason, the proposed system with small dimensions manages to reduce the main disadvantage of most

active treadmill interfaces – the need for a large walking area [8] – and ensure proper integration in a full immersive CAVE system by making it ideal for future immersion needs.

Based on the experimental study and results presented in this article, we achieved an omnidirectional walking for navigation in 3D VE by implementing a new locomotion interface and building an intelligent control. The preliminary test results will help future development of already existing domains by opening a path to new ideas and trends for more applications which integrated visions about Internet of Things, and also will contribute to VR locomotion interfaces evolution, which represent in our view a huge step making the Internet of Things to become a reality very soon in the next years. Moreover, our preliminary results show that the interaction between user and real/virtual objects is enhanced and it represents the main vision of the Internet of Things. Hence, our new locomotion interface will improve in the same time the quality of humans lives.

3 Proposed Prototype and Methodology

In order to answer the main research question addressed in this paper (*How to build a new locomotion interface with small dimensions by achieving an omnidirectional walking for navigation in 3D VE based on a complex control through AI methods, i.e., neural networks?*) we propose a modular prototype and describe next the functionality of each module. An overview of the proposed prototype was presented in Fig. 1.

The proposed prototype is to allow a user to endlessly walk in a VE in any direction, while he is on a real interface that compensates his motion. Our first scientific challenge in development of the omnidirectional interface was to make a completely immersion of the users and for this purpose a new method to control this interface was implemented.

Simulation Apparatus - We have built the locomotion interface based on a set of devices. The main device of our approach is a walking compensation device, based on an ordinary treadmill adapted for VR purposes. Also we combined other devices for building the prototype, such as: the Optitrack Motion Capturing System to track the human walking. In order to implement the control of the treadmill related to the VE of the application, we designed a simple test scenario that simulates a surfaces with hilliness (see fig. 1, a), left). The display and rendering graphics scenes are done in an immersive CAVE system to provide a whole body immersion and a strong visual feedback. Using this system, the VE scale and the human interaction become equal.

The omnidirectional compensation device – We have adapted an ordinary treadmill with the following dimensions for the surface area: length – 150 cm, width – 50 cm into an omnidirectional device. To achieve an omnidirectional walking for navigation we had to design and to build a mechanical support with two degrees of freedom (2-DOF) that has the following dimensions: the height of mechanical support is 50 cm, the upper surface is by 80 cm (L) and by 50 cm (W) and the upper surface is a cylinder with a diameter of by 50 cm (see Fig. 2, right). Then classical unidirectional treadmill was fixed on it, (see Fig. 2, left) and the new device became an omnidirectional compensation device with three degrees of freedom (3-DOF= 2-DOF

of mechanical support + 1-DOF treadmill). The whole prototype was simulated using CAD parts in order to build a good solution. The electrical part of the system was modeled in Matlab Simulink.

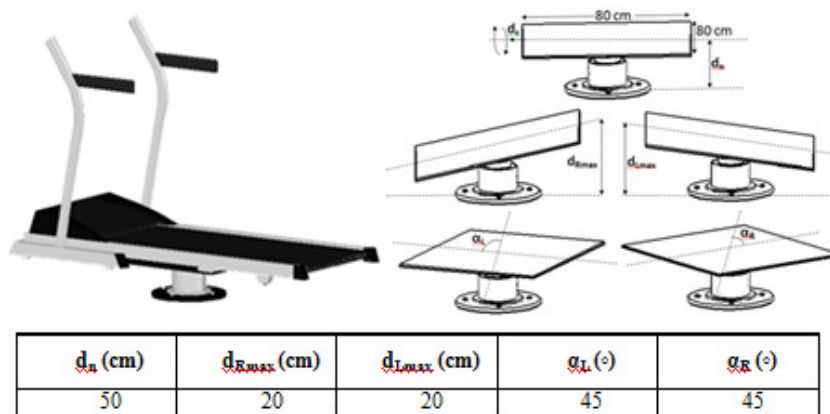


Fig. 2. The 3D model of the interface and the dimensions of the mechanical base

Three motors were used: one that actuates the treadmill belt and others two for mechanical support of treadmill: one motor to rotate left/right the whole platform and another one motor to tilt up/down the platform. One motor actuate the belt of the treadmill in order to compensate the user walking and another motor actuate the whole base for compensating the change of direction in walking. The first motor is a DC motor of 180 V, 7.5 A, 2 hp, 3000 rpm. Motors of mechanical support are EC motors of 48 V, 9.38 A, 400 W, 5370 rpm. To detect the sense of rotation for the motors are used optical encoders TIRO 1000. This sensor is coupled to the motor and detects the sense and also the speed of rotation by incrementing or decrementing a position number related to a reference value [13]. Hence, the user can navigate by walking on the surfaces of the VE into omnidirectional way on a real omnidirectional treadmill. Our system is able to rotate accordingly to cancel the turning motion when the user intends to change the direction of walking. In order to give user a feeling of safety, the hand supports of the original treadmill were not removed.

The Optitrack Motion Capturing System – A motion tracking system was needed to recognize the motion of the user's feet and maybe also body and then change the view accordingly and the whole platform is rotate. Therefore, we used a passive optical system that use markers coated with a retro-reflective material to reflect light back to the infrared cameras (IR). This system presents the following main advantages: high update rates, low latency and scalable to fairly large areas. In our experiments 12-IR cameras were used for data capture (see Fig. 1, a) right).

VE of the test scenario – We designed a simplest VE using Blender tool, because it is an open source tool. The VE simulates a track with mix surfaces: flat and surfaces with hilliness. The track from scenario has a square shaped, with a length of 4 km and a width of 10 m, with two traffic lanes (Fig. 1, b)). There are two types of hilliness,

with different angles of inclination (Fig. 1 c)). The human position on the track is given by a simplest virtual avatar (as it can be seen in the Fig. 1, a) left).

4 Experiment and Results

In order to control the sense of motors we use an algorithm implemented with neural networks. A neural network can be designed to perform a specific task and it need to be trained before it can be put in use. Matlab software was preferred to perform the computation, using the Neural Network Toolbox™.

The inputs of the algorithm are extractions of features from a set of data. Data were recorded from six users when they performed a real scenario similar with proposed VE. We tracked the position and orientation of users feet using the motion tracking system. Then we process data in order to extract the angle between the foot and tibia and also feet orientation related to a reference position for right and left rotation of treadmill. Extracted angles and feet orientation were data inputs for a neural network. A feed-forward neural network with one hidden layer of ten neurons is used. Also we modeled the used motors in Matlab Simulink in order to obtain the positions of the motors related to a reference factor and a parameter for the scenario, i.e. used to tilt the platform depending on the inclination angle of hills scenarios.

For choosing the number of neurons, the neural network is trained in Matlab and the number of neurons in hidden layer is reduced until the error can be accepted.

When training multilayer networks, the general practice is to first divide the data into three subsets: training set, validation set and test set [1]. Figure 3 depicts the training process for the proposed neural network, showing the confusion matrices for the training, validation, test and for all phases. For the test phase the accuracy of the neural network is 88,9 %, representing the percentage of correct classifications.

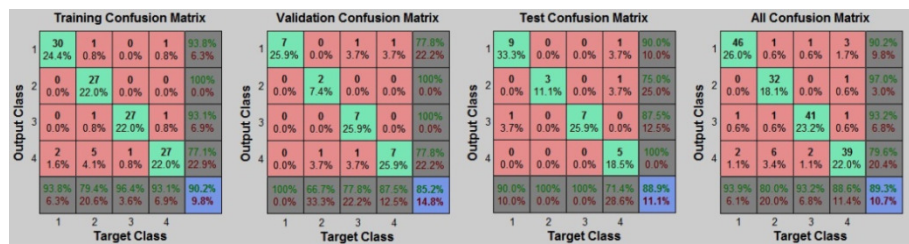


Fig. 3. The confusion matrices for the training process.

In Figure 4 (left) it can observe the mean square error during 17 epochs for the phases described above and for all steps the mean square error value decreases, the optimum value for the validation phase being obtained after 11 epochs. In Figure 4 (right) the gradient and the validation checks plots are illustrated. The value of the gradient after 17 epochs is 0.019608. The training process will stop when the validation checks reach 6 (the default value).

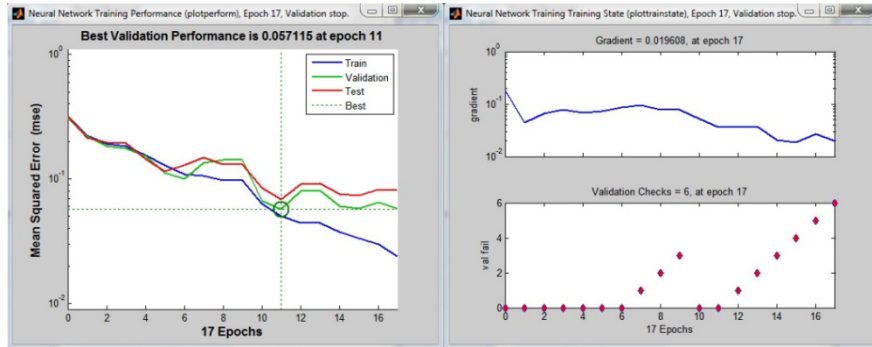


Fig. 4. Validation performance for neural network. Gradient and validation checks

After the training of data we tested the prototype in VEs in offline functionality for checking the solution. We checked the solution with new data recorded from the users. Each user performed three scenarios: (1) normal walking, (2) alert walking, and (3) mixed walking. We tested and checked the prototype in a VE in order to see the avatar behavior and also the control of treadmill (see Fig. 1, a)).

In normal walking good results were achieved with low errors for both the control of treadmill and avatar behavior. The results highlight that the mixed walking scenario presents errors due to fluctuation of walking speed. These errors are caused also of lost markers of the motion tracking system. In alert walking scenario some errors was registered, but less than in the mixed scenario. According to [15] the errors could be reduced if data are filtered previously to use after for testing the prototype.

5 Concluding Remarks and Future Works

In this paper, we present a system for omnidirectional navigation in VE and an algorithm is developed for controlling this interface using a feed forward neural network. Our goal was to develop an interface that allow an endlessly walk for a virtual avatar, while the real user move in a limited workspace in any direction. We designed a simple test scenario that simulate a surfaces with hilliness and a CAVE system was used as display to provide a whole body immersion and a strong visual feedback. In order to test the interface we propose a method for controlling the system using a neural network. The ease of use, simple structure and robustness are some advantages of the neural network controller, overcoming the limitations of PID controllers, like instability, late response and poor control performance. The preliminary results show the feasibility of the system was achieved.

The presented system is an improvement over current implementations, providing a solution for navigation in VEs with a small dimensions interface and enhancing the user immersion.

Future work includes a better control of the interface by implementing a system that recognizes the user intentions of walking. We intend to develop a complete virtual system for navigation with application in actual and future areas of interest.

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