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Cyberwalk: An advanced prototype of a belt array platform

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Abstract

The quest for an ideal floor which compensates the motions of a person walking in the virtual environment exists since the first human entered the virtual space. In this paper, an advanced model of a belt array platform, the Cyberwalk, is introduced. The prototype platform shows the increased performance of the system: High speed motion in both directions, almost unlimited upscalability of the system, synchronous speed of the belts, high stiffness and high load on the whole surface.

1 Introduction

The challenge to construct a floor which compensates the motions of a walker in the virtual world has produced various solutions. The idea to enable a person to walk freely in the virtual world - no matter how big the virtual space is without the use of metaphors (like flighsticks) - has excited researchers ever since. Many innovative approaches can be found such as the Gaiter System [15] which tracks and evaluates the users movements to generate motion in the virtual world without using a specially prepared floor. But the real movement is still limited by the room dimensions. The GaitMaster [9] uses footpads which follow the users motion and is able to simulate walking also on uneven terrain but turns are difficult to realize. A foot follower which allows this full turning capabilities is described in a former publication of the author [13]. To enable the user to move into any direction and in any pose he wants (also crawling), solutions were found which set the whole ground underneath the walker in motion with the goal to recenter the user. The energy to move the ground can be either produced by the user itself or with actuators. In the first case, the person stands inside of a sphere or on a spherical calotte. As soon as the person moves, a recentering momentum acts on the sphere which is generated by gravitation. This principle was realized with the Cybersphere [5] and the Virtusphere [10] which both use closed spheres. The Ball-Bearing Disc [6] is an example of a spherical calotte.

In the second case the floor is moved with actuators. The BAT [11] which is also described in a patent application by the Max Planck Institute [4] uses an array of balls which are actuated by a belt. This belt is placed underneath the ball array and can rotate around its axis, thus, the motions of the belt and the turntable are summed up in the balls. The BAT is capable of running a toy robot on its surface. An advanced model of a ball array platform was presented by our research group (Cybercarpet [12], [14]) which is able to demonstrate full speed walking of a human on the platform and apply downscaled GPS-Trajectories on a vehicle on the platform which were previously recorded by a human walker.

The Circula Floor [8] is made up of independent elements which travel from behind the walker to the front and form a new consistent floor. The omnidirectional treadmill (ODT) [3] uses two orthogonal belts which are made up of rolls and thus add the velocities. Finally, the Torus Treadmill [7] first showed a working prototype of an array of belts which form a torus and thus are able to apply independently velocities in X and Y direction. The application from Virtual Space Devices Inc [1] seems to use a similar principle although the used technology is not available to the public. The approach using an array of belts which is shaped as a torus is a very promising approach, although several problems have to be solved to build a platform which meets the requirements with regard to size, speed, noise, vibration, gapless actuated surface and seamless integration.

The prototype which is presented in this paper shows an optimized approach of a belt array platform which meets all the requirements which are necessary to create a deeply immersive environment.

2 The Cyberwalk

2.1 Basic principle

The basic principle of a platform using belts which form a complete torus has been described before ([7], Patent [2]) and shall only be mentioned in brief at this point.

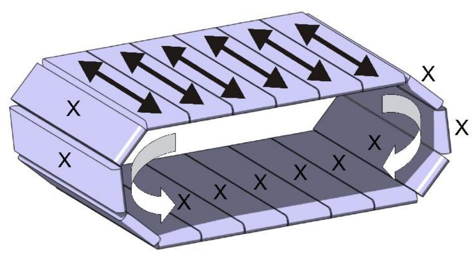

Figure 1. Platform principle.

Figure 1 shows the belts which form a torus. All the belts form a big chain. As soon as a belt segment is conveyed to the upper part of the belt, it is switched on (arrows). At the end of the surface, the belt is switched off (X) to prevent failure of the belt system which can not be operated vertically. By combining these two velocities, any resulting direction can be generated. The size of the walkable surface strongly depends on the maximum allowable acceleration on the walker which has to be below the thresholds of perception at any time. Our project partner, the Max Planck Institute in Tübingen is in charge to evaluate the restrictions of human perception.
As seen in previous approaches, there are several issues which have to be respected when such a platform is constructed:

- Speed and acceleration: The platform has to be able to reach the speed of a human walker and must be able to accelerate faster than a human does to provide control capability and emergency stops
- Adequate size: The platform has to be as big as necessary to realize acceleration restrictions and maximum speed
- Stiffness: The platform surface has to be comparable to the usual floor one is standing on. There may be no bending or step-stimulated vibration
- Gapless surface: The surface needs to be completely consistent, gaps have to remain smaller than the smallest corner of the shoe, the ideal is a seamless transition from one belt to the next
- Silent: The platform has to be very silent, all noisy components should be either encapsulated or displaced away from the platform itself
- Vibrationless: The whole system has to take care of unwanted vibrations which occur when moving heavy masses over rails e.g.
- Integration: The platform should fit in any common VR-Environment such as CAVE or HMD with marker-based or marker-less tracking

Within these issues there are several contradictions which have to be overcome by researching technologies and engineering new solutions.

2.2 Construction of the Cyberwalk

The Cyberwalk is built up of the following components:

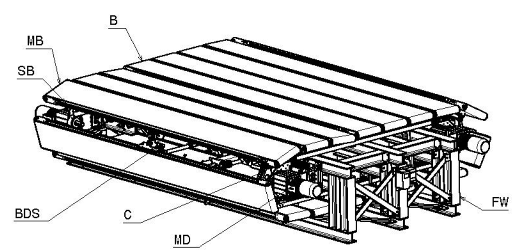

Figure 2. Platform main components

The main drives (MD, 4 drives in total) actuate the chain (C) which has the belts (B) mounted on top. A hydraulic system actuates the belts via the drive system (BDS) which is mounted on the inner side of each belt. The whole system is mounted on the basic framework (FW). All these systems will be described in detail in the following.

2.3 Platform characteristics

The platform is able to achieve 0.5 m/s (after planned extension: 2m/s) in direction of the chain and 2m/s in direction of the belts. The walkable area is 4.7 to 2.6 meters and can easily be extended by adding further modules (4.7 to 4.6 meters planned). The height of the platform is approximately 1.4 meters. An interface for a high level control is available, the tracking system has already been tested for compatibility and robustness.

3 Improvements

3.1 Shape of main chain

One of the main problems of chains with big flank pitch is the polygon effect and in addition to that a jump in curvature when the chain element moves from the linear section to the circular section.
The polygon effect leads to a discontinuous motion on the tight span and irregular shaking in the slack span. It also causes vibration and impacts especially on the drives and gearboxes. The jump in curvature has a great effect on the masses which are mounted on the chain, here, the belt systems. For example when a belt segment leaves the drive wheel towards the linear rail, the belt system which is mounted on top of the chain keeps its angular momentum due to the laws of mass inertia. As the belt segments are mounted on the chain without gaps, the belt system slaps against the precedent belt as soon as the speed of the platform reaches a certain level (occurs already far below 2 m/s).

To overcome these limitations the trajectory in which the chain is conveyed is shaped in a special way.

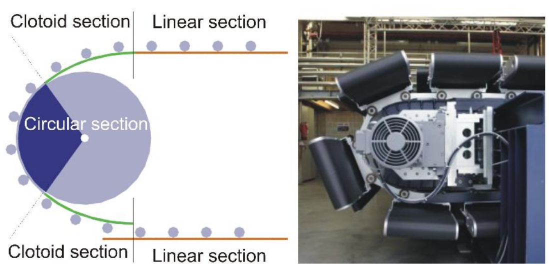

Figure 3. Chain Trajectory

Figure 3 shows the setup of the drive. On each end of the chain bolts a track roller can be found. These rollers include ball bearing and the surface is made up of Aclan, a special damping material which allows smooth and noiseless operation. Each chain link is thus bedded on four rollers. These rollers are guided on rails. They are actuated in the following way: The rollers move from the linear rail on the upper side towards the clotoid rail without a jump in the curvature of the surface. The belt which is mounted on top of the chain link is accelerated smoothly and the angular momentum is increased. Then, the drive wheel gets grip of the chain bolt and at the point where the curvature of the clotoid rail and the circular wheel are equal, the chain is carried on by the drive wheel. On the lower side, the chain is guided by the drive wheel until the curvature is again equal to the curvature of the clotoid rail. The whole system decelerates the angular momentum smoothly. The rollers are guided by the clotoid rail until they are supported by the lower rail. An ideal choice of parameters ensures a good proportion between diameter, accelerations and engagement on the drive wheel. On our prototype, the drive wheel has an effective diameter of 653mm with a resulting height of approximately 700mm between the two chains.

3.2 Basic framework

The basic framework of the platform is designed in a way to overcome the limitations of load and size. Figure 4 shows the front, side and top view.

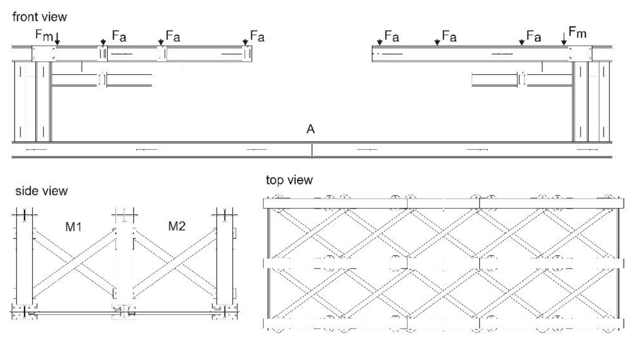

Figure 4. Framework structure

One of the main aspects is the fact that the cantilever beams reach from both sides to support the platform and leave a gap in the center. The forces F_m are the main loads which are generated by the chains which bear the belts. The forces F_a are additional, but much smaller forces which are generated by rollers which support the belt. The big force F_m is directly applied to the very rigid structures on the outer edge of the platform, the cantilever beam only needs to bear the forces of the supporting rollers.
Moreover, the structure itself ist designed in a modular way (M1, M2... Mn and separation at joint A as shown in figure 4) so keep production cost lower and ensure easier assembly. Even a certain mobility of the whole system is granted by this design. The cross beams grant high stability and stiffness as well as the possibility for an assembly with low tolerances. The gap between the two sides is used to mount the energy chains to actuate the belt systems.

3.3 Actuation of the chain

The actuation of the chain is a very crucial element of the whole platform. The goal is to move the whole system smoothly and to avoid jerks and vibration. When reversing a standard chain, the change of tight span and slack span causes jerks and in case the clack span is on the upper side, a lift off of the chain segments can be found after the driving wheel. This characteristic is not suitable for our purpose. Another requirement derives from the fact that the gap between the cantilever beams is used to transmit the energy which is needed to actuate the belt systems. Thus a shaft between the two sides of the chain wheels is not possible. These limitations lead to a 4-drive setup, one at each chain wheel. The control of the drives ensures that only the motors which are in the direction of the platforms motion are actuated. Thus, the tight span is always on the upper side of the chain. The actuating drives are connected via a frequency control line which ensures synchronous operation. This digital shaft prevents the platform from severe damage which would occur of the two chains would have different speeds. The two drives which are in the opposite direction of the platforms motion create a counter momentum which keeps the whole chain under tension even if the platform ist standing still.

3.4 Belt construction and alignment

To create a highly immersive environment, the floor a walker is standing on has to be very homogenous and must provide similar characteristics like ordinary floors. As soon as the walker touches parts of the floor which are not actuated, the immersion is broken. In case of the belt array, this is in particular the case if there are gaps between the belts. Normally, it is impossible to align single belts without a gap between the belts because the whole system has to be mounted and powered at some point. In our prototype, we overcome this limitation by introducing a coupled pair of belts, namely the main belt (MB) and a support belt (SB) which can be seen in figure 5.

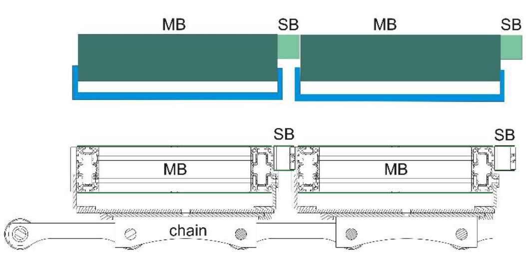

Figure 5. Belt alignment

The support belt SB is of smaller height as the main belt MB, thus there remains a lot of space underneath the small belt which can be used for fixations and actuators. Moreover, the support belts SB are a little bit shorter than the main belts MB. In this way the main belts can be beared with a standard roller which is cost efficient and allows exact adjustment of the belt track.

3.5 Belt actuation and traction

The actuation of the support belt SB and the main belt MB must be conducted in a way that these two belts always run at the same speed as well as all belts have to run at the same speed. Moreover only the belts which are on top of the platform are allowed to run.
To achieve the synchrony of the main and support belt, both belts are actuated via the same drive roll DR as shown in figure 6. This drive roll is actuated via a toothed belt by a hydraulic motor HM. A special valve system is mounted on the hydraulic motor and allows bypassing of the hydraulic fluid, which means switching the motor on and off. Using this valve, the motors can be switched on and off depending on their place on the platform. The hydraulic valve is actuated with a pneumatic system, one way restrictors allow different speeds for opening and closing the valve. In this way, the closing procedure can be well adjusted to avoid pressure peaks in the hydraulic system.

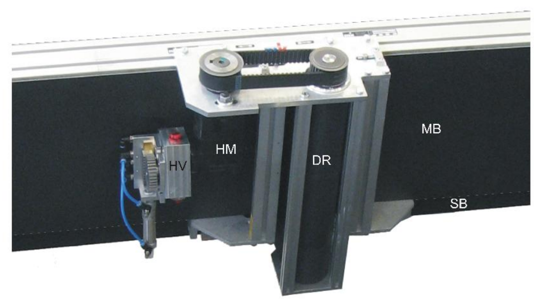

Figure 6. Belt actuation

The next challenge is to ensure that all belts are running at the same speed no matter how much load is exposed to one single belt. All the belts are connected with the hydraulic system in a serial manner. This means that all the motors, which are not on top of the platform are switched to bypass and let the hydraulic fluid pass with virtually no pressure drop. The bypass of the motors which are on top of the platform is closed, the fluid powers the motor. As the fluid has to pass all the activated belts, the speed of the belts has to be the same. The person which is walking exposes the belts to varying loads on different segments. Due to the serial alignment, the pressure drop on the belts with load will be higher, the hydraulic fluid releases its energy exactly at the point where it is needed without any delay. The fluid volume is kept constant by the aggregate, due to mass inertia of the hydraulic pump an additional load on the platform results in a rise of pressure in the system, but no significant drop in engine speed can be detected at the pump.
The traction of the belt is also an important point. As there are lateral forces on the belt, the belt has to be kept on track. Due to the length this can not only be done by pure tension.

The belts are equipped with a trapezoid guiding bar which is welded on the lower side of the belt and kept on track by special grooves.

3.6 Haptic issues

Vibration, noise and stiffness are some of the most important issues of the platform which could disturb an immersive environment. The damped rolls on the chain links and the absence of jerks and slapping segments lead to a very smooth operation of the platform. Some noise is generated by the pneumatic system but as the exit air is collected and treated the noise level is very low. The hydraulic aggregate which is the loudest component emitting 80 dB can be placed in a separate room. The fans of the main drives are still quite noisy as they run at full speed at any time. Additional frequency controllers will slow down the fans to reasonable speeds in the future. Measurements of the temperature have shown that 20% of the actual fan-speed would be enough to cool the motors. As soon as the platform is placed in its final location, the noise level will be measured. It is estimated with values between 45-50 dB.
The belt systems have quite a large span of approximately 5 meters. When a 100kg person walks on these segments, there would be quite some bending because the belt segments need to be a lightweight construction to keep the amount of moving masses low. Additional rollers support the belts and take the additional load. Experiments with several persons on the platform have shown that the platform can easily bear the additional weight and the rollers prevent the structure from bending.

4 Applications

There is a large sector of applications which is open to such a device. Figure 7 shows the main fields of application from a scientific point of view.

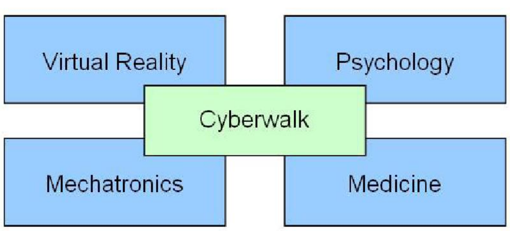

Figure 7. Fields of application

The research of human behaviour and the principles how the human controlls its motions is still a very challenging task. With a device like the cyberwalk, the reactions of the subject can be tested in a reproducible way. Different groups subjects can be tested and compared e.g. healthy ones to a group with a special illness. These results can guide us to a better understanding of the mechanisms inside our body and open up new ways of treatment. This is only one example of an application, many more are possible.
The use in VR-Applications is one of the most obvious applications of this device. There is a large variety of scenarios where it is very desirable to be able to walk naturally in an environment. On the one hand it is the most comfortable method to navigate trough space, on the other hand the perception of the environment with respect to its dimensions is superior.
There is also a commercial field of application which is open to these devices and ranges from amusement parks and fitness studios to the training of military personnel. After further development from the mechatronical point of view such a device could be even available to private households with sufficient space and be used in highly immersive computer games.

5 Further work

The platform is already running at speeds of 0.5 m/s in direction of the chain and 2m/s in direction of the belts. The velocity of the chain can be increased as soon as the lower guiding rails are optimized. The targeted speed is also 2 m/s. At the moment, the prototype consists of two modules (M1 and M2) which results in a walking area of 4.7 to 2.6 meters. To provide a platform which is suitable for perceptual studies and walking freely in the virtual space, additional segments will be added to achieve a walking area of at least 4.7 to 4.6 meters. Depending on the results, sizes up to 10 x 10 meters would be possible at reasonable cost.
The motor fans have to be equipped with frequency controllers which are coupled to the temperature on the motor's cooling fins. Thus we ensure an optimal cooling of the motors and the lowest noise level which is possible.
All the elements of the platform have to be fine-tuned to generate an optimal result. Additional security equipment will be installed and the interfacing to any computer via a DLL is planned. The control and tracking system has already been tested on the Cybercarpet (Cybercarpet [12], [14]) and will be implemented as soon as the additional segments are installed.
Finally, the platform has to be integrated in a scientific research program which will be suited at the Max Planck Institute for Biological Cybernetics Cognitive and Computational Psychophysics - Dept. Bülthoff.

6 Conclusion

The platform presented in this paper shows very favourable characteristics and proves the concept. On the one hand, the platform is already able to reach reasonable velocities and is ready for the application of even higher speeds. The final walking area of 4.7 to 4.6 meters is quite large, as far as published and known to our group the biggest motion platform existing at this moment. The concept is fully modular and allows an easy upscaling of the platform. The whole concept is optimized with respect to upscalability. An innovative alignment of the belt systems overcomes former problems with belt fixations and gaps between the belts. The actuation of the belts ensures smooth and constant velocities over the whole surface. Vibrations can not be perceived when standing on the platform. The noise level of the platform itself is very low and by using well damped earphones of no issue to immersion.

7 Acknowledgements

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References

[1] Virtual space devices inc., http://www.vsd.bz/.

[2] D. Carmein and A. Arbor. Patent no. ep 0 948 377 b1, 1999.

[3] R. P. Darken, W. R. Cockayne, and D. Carmein. The omni-directionaltreadmill: A locomotion device for virtual worlds. In *in Proc. ACM UIST*, page 213221, 1997.

[4] M. Ernst and H. B. for Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. Munich GER. Fördereinrichtung insbesondere für ein laufband, Filed 2004 Published 10-2005. DE 102004 016 429 A1.

[5] K. J. Fernandes, V. Raja, and J. Eyre. Cybersphere: the fully immersive spherical projection system. *Commun. ACM*, 46(9):141–146, 2003.

[6] J. Y. Huang. *Transactions on multimedia*. IEEE, vol. 5, no. 1 edition, March 2003.

[7] H. Iwata. Walking about virtual environments on an infinite floor. In *Proc. IEEE Virtual Reality Conference 1999*, page 286, 1999.

[8] H. Iwata, H. Yano, H. Fukushima, and H.Noma. Circulafloor. In *in Proc. SIGGRAPH 2004*, page 3, 2004.

[9] H. Iwata, H. Yano, and F. Nakaizumi. Gait master: A versatile locomotion interface for uneven virtual terrain. In *Proc. IEEE Virtual Reality Conference 2001*, page 131, 2001.

[10] N. N. Latypov and N. N. Latypov. The virtusphere. http:www.virtusphere.com, 2006.

[11] A. Nagamori, K. Wakabayashi, and M. Ito. The ball array treadmill: A locomotion inter-face for virtual worlds. In *Workshop on New Directions in 3D User Interfaces (at VR 2005). Bonn, Germany*, 2005.

[12] M. Schwaiger, T. Thümmel, and H. Ulbrich. A 2d-motion platform: The cybercarpet. March 2007.

[13] M. Schwaiger, H. Ulbrich, and T. Thümmel. A foot following locomotion device with force feedback capabilities,. In *Proceedings of VIII Symposium on virtual Reality, pp. 309-321, Belem, Brazil*, 2006.

[14] M. Schwaiger, H. Ulbrich, and T. Thümmel. Cyberwalk: Implementation of a ball bearing platform for humans. In *Proceedings of 12th international Conference on Human-Computer interaction, Bejing 2007*, 2007.

[15] J. N. Templeman, P. S. Denbrook, and L. S. Sibert. Virtual locomotion: Walking in place through virtual environments. In *PRSESENCE Vol. 8, No. 6*, pages 598–617, 1999.