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# Real walking in virtual environments for factory planning and evaluation

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**Abstract**

Nowadays, buildings or production facilities are designed using specialized design software and building information modeling tools help to evaluate the resulting virtual mock-up. However, with current, primarily desktop based tools it is hard to evaluate human factors of such a design, for instance spatial constraints for workforces. This paper presents a new tool for factory planning and evaluation based on virtual reality that allows designers, planning experts, and workforces to walk naturally and freely within a virtual factory. Therefore, designs can be checked as if they were real before anything is built.

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## 1. Introduction

Since years, buildings, production lines, and production facilities are planned and designed using dedicated software, like Computer-Aided Design (CAD), Computer-Aided Architectural Design (CAAD), or Building Information Modeling (BIM). While these systems offer good support for architects and engineers to plan and design installations, they are less suited to address and evaluate human factors in design. Such human factors are for instance the perception of sizes and distances, level of comfort, but also spatial constraints at a workplace, which could be naturally experienced in its dimensions by the possibility of real walking. However, in particular distances and walking times are hard to evaluate with monitor-based systems, and thus also virtual reality (VR) systems are employed. In such systems, the user is immersed in computer-generated environments and can see objects in real size.

However, the perception of sizes and distances is limited by the fact that navigation is still done using mouse and joystick. It was shown by Usoh et al. [1] that such a navigation does not address the natural human perception of real walking. Real walking allows a natural navigation [2] together with better orientation [3] in virtual environments. In general, real walking is superior to other navigation metaphors such as mouse or other gestural walking (e.g. walking-in-place [4] or stepping-in-place) [1]. Virtual environments with real walking capabilities are superior to any other ways of representation because of the following reasons:

- They allow an immersive experience at a very early planning stage without the effort of building a physical mock-up. Thus, it is possible to make multiple iteration steps in the development process without extending the development time and to reduce the costs significantly, see [5].
- Since walking is the most intuitive tool for navigating in virtual environments, also non-experts - which are in most cases the later users of the product - can be integrated in the development process.
- Virtual Reality easily allows the evaluation of human factors in new designs, such as walking distances, space requirements of workers, but also e.g. an early evaluation of human manufacturing and assembly tasks using an MTM method (methods-time measurement).
- Manual operation processes in industry frequently require also walking of a worker, e.g. in a Chaku-Chaku setup [6], where the user is transporting the product or other objects.
- Finally, immersive environments can be used for training purposes prior to the finalization of the real installation.

Real walking becomes problematic when the virtual environment is larger than the physical space, e.g. for complete shop floors. To overcome this problem, mechanical locomotion devices such as e.g. the Torus Treadmill [7] or the omnidirectional treadmill [8] were developed. These locomotion de-


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vices allow walking over large distances in the virtual environment, but keep the user in a small space within the real world. However, such devices are costly, allow only a single-user experience, and still do not provide a fully realistic sensation.

Thus, recent research is based on so-called Redirected Walking [9], which "compresses" large virtual environments into a smaller physical room by applying a subtle redirection to the user. These systems allow real walking without any additional mechanical interfaces and thus offer the highest possible immersion. Since this approach becomes increasingly mature, the goal is now to apply it to real industrial use cases, such as training or emergency scenarios, in which the perception of distances plays an important rule. This system allows natural and free walking inside a virtual factory even when the physical room, where a user is actually located, is smaller than the virtual factory. This spatial compression is based on redirected walking, a technique that allows free walking in large virtual environments without using locomotion hardware like treadmills. Since even large virtual environments could be experienced by redirected walking in a limited physical space, redirected walking should be applied now for factory planning and optimization of factories. However, this imposes the reserach question which redirection algorithms could be applied for this application case and how the controller needs to be modified to exclude non-suitable redirection techniques.

Therefore, the paper's main contribution is to apply this new system to factory planning and evaluation, based on VR that allows designers, planning experts, and other work-forces to walk naturally and freely within a virtual factory. The paper shows the first application of redirected walking to a real problem in production industries. Real walking and experiencing the virtual environment from an egocentric perspective is in particular important for evaluating the user behavior e.g. for MTM, which currently can not cope with real walking. This paper shows how redirected walking can be optimized for free walking in virtual factories. The resulting system allows improving and checking models very early in the design process – before anything is built – and thus avoids costly redesigns at a later stage.

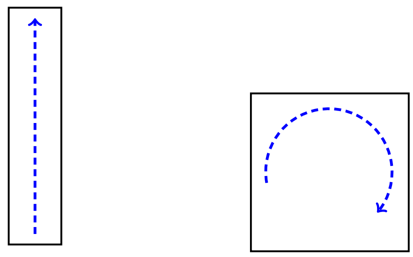
The paper first introduces the field of Redirected Walking (RDW). After showing a typical system for unlimited walking in virtual environments, it describes which RDW algorithms can be used for an application in factory planning and evaluation. The remainder of the paper describes the currently available interaction capabilites of the system. Finally, the paper concludes with an outlook on future work.

## 2. Background

### 2.1. Redirected walking

Technically, enabling a user to really walk inside arbitrary virtual environments – including virtual factories – is best realized by letting the user walk in a physical/real room. A tracking system can be used to track the user's viewpoint in real time and render the virtual environment from that perspective. Typcially, the rendered scene is shown to the user using a head mounted display (HMD). The HMD blocks the user's sight on the real room and just lets him see the virtual environment.

However, this approach has the disadvantage that the size of the real room (or the tracked space) limits the size of the virtual environment that can be walked through. In order to avoid costly or unnatural mechanical locomotion interfaces and still be able to walk freely in arbitrary virtual environments, Razzaque et al. [9] proposed RDW. This is a method that uses a set of techniques to guide a user on a different path in the real room than what he is walking in the virtual environment. Primarily, RDW manipulates the visual output presented on the HMD. For instance, by slowly rotating the virtual environment about he user while he is walking along a straight path. If this rotation is below the human threshold for sensing orientation or movement with non-visual cues, the user will not notice the rotation and walk on an arc in the real room. I.e. the user gets redirected. The fundamental psychological foundation for RDW is that vision generally dominates other modalities (e.g. proprioceptive senses) of perception [10,11].



(a) Virtual environment (b) Real room

Fig. 1. Working principle of redirected walking. The dashed blue line indicates a user's path. The user believes that he is following the straight path in the VE (a). However, because the VE is continuously and imperceptibly rotated clockwise about the user, he actually walks on an arc in the real room (b).

This working principle is illustrated in Fig. 1. Here, the user walks along a straight corridor in the virtual environment. As the scene is slowly rotated clockwise around he user, he actually follows a circular path in the real room. I.e. visual dominance over proprioceptive senses causes the user to compensate his real walking path without noticing. This example also shows how RDW can be used to explore a virtual environment that is longer than the longest straight line fitting into the real room.

### 2.2. Redirection techniques and control

Different redirection techniques were proposed so far. For instance, the redirection technique that is used in Fig. 1 is referred to as curvature gain because it makes users walking on a curved path in the real room, while walking on a straight line in the virtual environment. For these sorts of redirection techniques it is important to know the gains. The gain is essentially the strength parameter of a redirection technique and given as the maximum applicable redirection without the user noticing the manipulation. Common redirection methods are:

- Curvature gain: rotation that can be added when a user is walking on a straight line, see [9,12,13].
- Rotation gain: scaling of the user's rotational movements like head turns or full body turns, see [9,12].
- Translation gain: scaling of the user's translational movement. I.e. the user's speed in the virtual environment is increased or decreased, see [12,14].
- Architectural illusions and change blindness: tricking the user's spatial memory or perception by using specialized