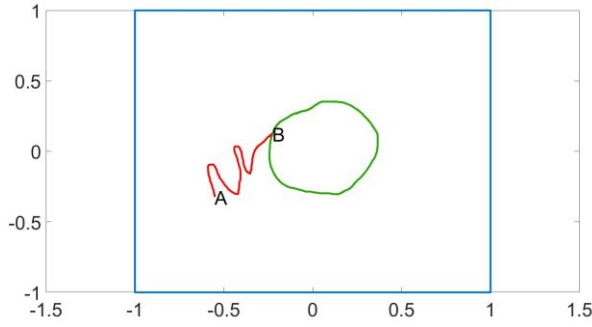# Mapping of Locomotion Paths between Remote Environments in Mixed Reality using Mesh Deformation

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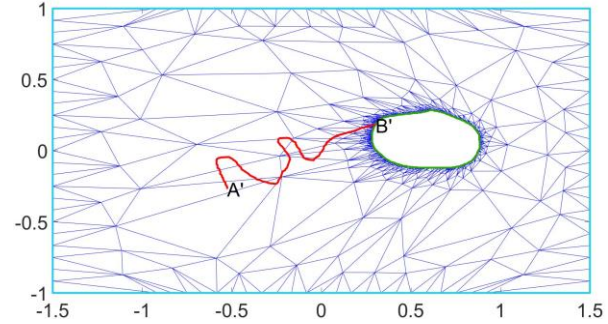nilanjan.sarkar@vanderbilt.edu

(a) Orthogonal 2D view of the user's room. User's walking path *AB* (red) towards a table/non-walkable object (green).
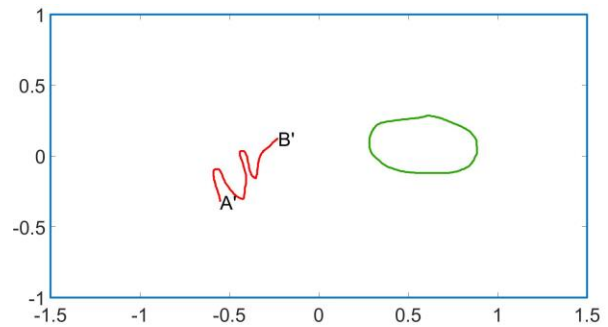
(b) User's avatar's path *A'B'* in its room when directly mapped from (a). Note the different dimensions of the table/non-walkable object and room from (a)
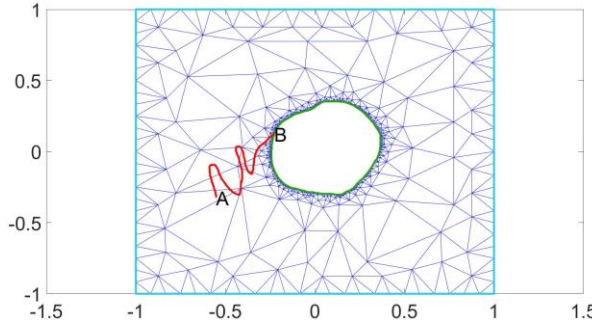
(c) Mesh generated for user's room in (a)

(d) Mesh generated in (c), deformed to the dimensions of the room in (b). Note the new equivalent path *A'B'* generated (red).

Figure 1: The above figures show the mapping of a user's walking path from their environment ((a) and (c)) to their avatar's environment using mesh deformation ((b) and (d)). We have used the deformation that minimizes the Dirichlet energy associated with the user's room's mesh subject to the boundary conditions of the avatar's room.

ABSTRACT

Remote mixed reality (RMR) allows users to be present and interact in other users' environments through their photorealistic avatars. Common interaction objects are placed on surfaces in each user's environments and interacting with these objects require users to walk towards them first. However, since the user's and their avatar's room's spatial configuration are not exactly similar, for a particular user's walking path, an equivalent path must be found in the avatar's environment, according to its environment's spatial configuration. In this work, we use the concept of mesh deformation to obtain this path, where we deform the mesh associated with the user's environment to fit to the spatial configuration of the avatar's environment. This gives us the corresponding mapping of every point between the two environments from which the equivalent path can be generated.

1 INTRODUCTION

In remote mixed reality (RMR), users can be represented in other users' environments by their photorealistic avatar, giving them the ability to interact with common objects in their environments. Many times, objects are placed over surfaces (tables, desks, furniture etc.) in one's environment and the user
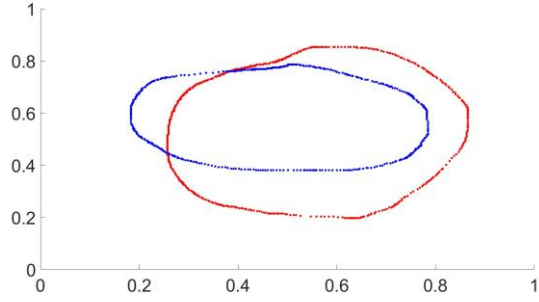
(a) Corresponding interior object boundaries of the user's (red) and their avatar's environment (blue) shown on the normalized 2D plane.
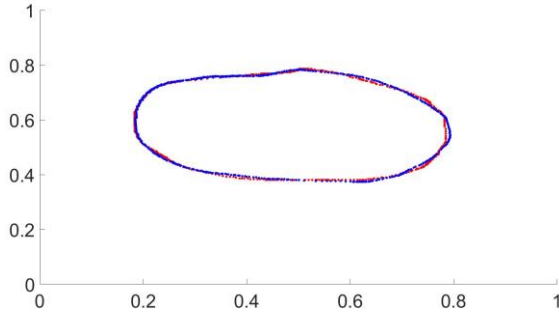
(b) The fitting of the user's interior object boundaries to that of the avatar's using non-rigid transformation technique. For each point on the avatar's object boundary (blue) there is a corresponding point of the user's object boundary after applying the transformation (red).

Figure 2: The above figures demonstrate obtaining the correspondence between different shaped interior object boundaries.

has to walk over to that surface in order to interact with it. However, in the user's avatar's environment this object may not be at the exact same location and a direct mapping of the user's locomotion path to the avatar environment will lead to the avatar in the wrong location for the interaction (Figure 1(b)). In this work, we introduce a solution to the above problem using the concept of mesh deformation.

2. CONCEPT OF MESH DEFORMATION FOR FINDING EQUIVALENT MAPPINGS

Current literature includes the use of local 3D tetrahedral meshes to redirect hand and body motion around similar shaped, but different interaction objects [1]. However, a direct application of these techniques to room-sized environments is computationally infeasible in real-time. Hence, we a use 2D mesh, obtained by orthogonal projection of the mesh obtained from the user's headset (Figure 1(c)). We then deform this mesh according to the avatar's room interior object and exterior boundaries. Each room can be considered to consist of walkable and non-walkable spaces and a room external boundary (blue outline in Figure 1). The interior non-walkable object boundaries, I_B, are the 2D external boundaries of all the

interior objects $\{ I_1, I_2 \ldots \ldots I_n \}$ in the room. The external boundary, E_B, is the 2D boundary of the room. For two given rooms, 1 and 2, we define interaction spaces M_1 and M_2 and find the spatial mapping function $f_M: M_1 \rightarrow M_2$ between them. Mapping will include a map $f_{IB}: I_{B1} \rightarrow I_{B2}$ between the interior object boundaries, a map $f_{EB}: E_{B1} \rightarrow E_{B2}$ between the external boundaries, and a map $f_W: W_1 \rightarrow W_2$ between the interior walkable mesh spaces of the two rooms. We assume that there exists a continuous bijective map for f_M. This simplifies the mapping and is a reasonable assumption to make because interior and exterior boundaries in both rooms although not exactly the same, will be of topologically similar shape.

2.1 Finding the corresponding mapping

We use the non-rigid ICP algorithm[2] to find $f_{IB}: I_{B1} \rightarrow I_{B2}$ (Figure 2) and $f_{EB}: E_{B1} \rightarrow E_{B2}$. For $f_W: W_1 \rightarrow W_2$, we generate a new mesh W_2 that has the same connectivity as that of W_1 by deforming W_1 such that its boundaries now coincide with the target boundaries I_{B2} and E_{B2} (Figure 1(d)). When finding W_2 from W_1 using mesh deformation, we generate the new vertex positions so as to minimize the Dirichlet energy associated with a mesh. A solution that minimizes the Dirichlet energy can be understood physically as a solution to a static spring system in which the distortion of each element (vertex position changes from W_1 to W_2) tends to spread out evenly on the whole mesh, and not concentrated to local area of the mesh giving a smooth deformation. Once f_W is obtained, the equivalent path is generated using the barycentric coordinates of the original user's path, but with the new deformed mesh vertices.

3. CONCLUSION AND FUTURE WORK

In this work, we have developed a mesh deformation technique for finding equivalent paths for different room configurations. This can be used by a user's avatar to follow their walking path in its environment. The generated equivalent path, however, cannot be directly followed by the avatar as sometimes the equivalent path may violate naturalistic walking constraints. For example, due to the change in path length, the avatar's step length may be greater than the maximum gait distance possible for a human when its steps are directly mapped on the equivalent path. It is important for the avatar to not violate these constraints, as it will reduce the naturalism of the avatar's motion. Thus, there are two main objectives: i) for the avatar to follow the equivalent path with minimum error, and ii) for the avatar to not violate naturalistic walking constraints. These objectives may sometimes conflict with each other. In the future, we will develop a multi-objective optimization (MOO) framework to satisfy these objectives and obtain the naturalistic walking path for the avatar to follow.

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[2]   Li, H. et al. 2008. Global correspondence optimization for non-rigid registration of depth scans. *Computer graphics forum* (2008), 1421–1430.