To link to this article : doi: 10.1109/VR.2015.7223344
URL : http://dx.doi.org/10.1109/VR.2015.7223344

To cite this version : Cailhol, Simon and Fillatreau, Philippe and Fourquet, Jean-Yves and Zhao, Yingshen A Multi-Layer Approach of Interactive Path Planning for Assisted Manipulation in Virtual Reality. (2015) In: VR 2015 IEEE Virtual Reality, 23 March 2015 - 27 March 2015 (Arles, France)

A Multi-Layer Approach of Interactive Path Planning for Assisted Manipulation in Virtual Reality

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***Abstract*—This work considers Virtual Reality (VR) applications dealing with objects manipulation (such as industrial product assembly, disassembly or maintenance simulation). For such applications, the operator performing the simulation can be assisted by path planning techniques from the robotics research field. A novel automatic path planner involving geometrical, topological and semantic information of the environment is proposed for the guidance of the user through a haptic device. The interaction allows on one hand, the automatic path planner providing assistance to the human operator, and on the other hand, the human operator to reset the whole planning process suggesting a better suited path. Control sharing techniques are used to improve the assisted manipulation ergonomics by dynamically balancing the automatic path planner authority according to the operator involvement in the task, and by predicting user's intent to integrate it as early as possible in the planning process.**

***Keywords*-Virtual Reality; Interactive path planning; control sharing; multi-layer architecture**

I. Introduction

Due to the increasing complexity of products and to the acceleration of product development, industry needs tools to test, during the design phase, a product at all the PLM stages with virtual prototype. The tests involving manipulation by a human operator can be performed in Virtual Reality (VR) simulations. One of the main issues is to find path for systems components to move.

We propose a collaborative path-finding system based on the interaction of a user immersed in a VR simulation and an automatic path planner inspired from techniques used in robotics. With our multi-layer approach, a human operator and an automatic system share control, while performing a manipulation task, to find the most suitable path.

II. State of the art

Two distinct strategies have been studied for industrial product assembly simulation using virtual prototypes:

1) Off-line simulations using path planning techniques from robotic research field. In this case, the human operator only defines the initial and final positions of the components to assemble and let the path planning algorithm run until a trajectory is found.
2) On-line simulations using VR applications. In this case, a human operator is immersed in a virtual environment including virtual prototypes of industrial product parts. The human operator is provided with the capability to handle and manipulate the product parts and performs the assembly task.

On one hand, the off-line simulations are time consuming; on the other hand, the cluttered 3D environments of on-line simulations may be hard to handle for the human operator because of sensory interfaces.

To overcome these limitations, An interactive path planner have been proposed to merge these tools using path planning techniques to assist the human operator in a VR assembly application [1]. This interactive planner still suffers from the processing time and possibility of failure of the automatic path planning process. Moreover, the interactions between human operator and automatic planner remain poor because of the different kind of information used by the two entities (geometric only for the automatic path planner, abstract concepts for the human operator).

III. Proposed VR manipulation assistance

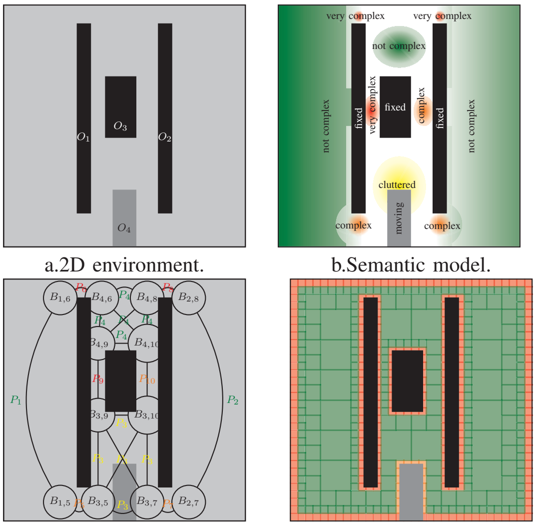
A. Multi-layer environment representation

To handle these issues we propose providing the planning system with abstract information such as semantic and topological information of. The environment layers are illustrated in Figure 1 with a 2D environment, but it stand the same for a 3D environment. The representation of he environment (Figure 1.a) is made of a semantic layer adding information to environment's objects and places (Figure 1.b), a topological layer made of a topological graph connecting environment places (Figure 1.c), a polyhedral model of the object and a cell decomposition of the free space (Figure 1.d). This information is used to speed up automatic path planning allowing so real-time interaction; but also for interaction to accurately interpret operator's actions.

B. Path planning process

With this multi-layer environment representation, we chose to handle a path planning query by splitting the planning process in two phases. Both of these phases involve the semantic information:

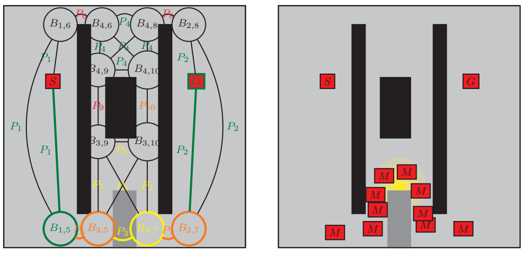
1) A coarse planning phase performed on the topological model of the environment. For this phase, the semantic information is used to define the costs of the topological graph's elements to control its exploration. The result of the coarse planning phase is a topological path (Figure2.a) split in topological steps (a step for each place crossed) marking the trajectory.



a.2D environment. b.Semantic model.

c.Topological graph. d.Free space decomposition.

Fig. 1. Different perceptions of environment for user and planner.



a.Topological path. b.Geometrical path.

Fig. 2. Topological and geometrical paths.

2) A fine planning allowing to refine the marking of each topological step. For this phase, the semantic information is used to chose the geometric planning strategy for each topological step.

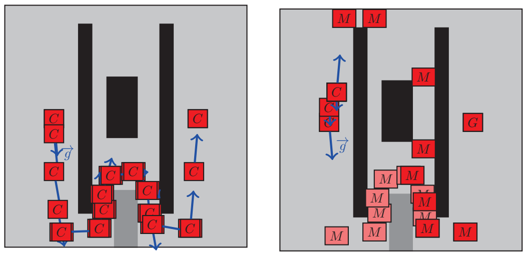
Finally, once both of these phases executed, the trajectory is completely marked (Figure2.b).

C. Interactions and control sharing

The automatic path planner described above assists a human operator immersed in VR simulation to perform assembly tasks. Thus we propose novel interaction modes to guide the user, but also, to let the user suggest new directions to the automatic path planner. The interaction ergonomics have been improved thanks to control sharing techniques inspired from semi-autonomous vehicle driving (authority sharing) and robot tele-operation (intent prediction).

1) Interactions: Two interaction modes allow the automatic path planner and the immersed human operator collaborating while performing the assembly task:

- the trajectory defined by the automatic path planner is used to guide the user through a haptic device. To do so, the guidance pulling the human operator is computed from a linear interpolation toward the next geometrical milestone (the next geometrical milestone being updated as the task is being performed Figure 3.a).
- the movements performed by the human operator are used to detect if he goes away the proposed trajectory at the topological layer. If so, his intent is predicted and used to re-plan a new path (Figure 3.b).



a.Guidance update. b.Path re-planning.

Fig. 3. Planning interaction modes

2) Authority sharing: The *H-mode* proposed in [2] has been adapted to dynamically balance the authority of the automatic path planner (by modulating the guidance norm) according to the user involvement. This allows having a strong guidance while the operator is following it, and a reduced one when he is exploring other paths.

3) Intent prediction: The intent prediction from [3] inspired us to define a way to predict user's intent at topological level and then use it to guide a coarse re-planning toward the user's preferred path.

IV. Conclusion

This paper presents a novel architecture for interactive path planning in VR simulations. This architecture is based on multi-layer environment model and planner. This architecture involves semantic topological and geometric information while path planning traditionally handle geometric information only. The contribution of such architecture is two-fold:

- First, it provides the user with real-time path planning assistance thanks to the semantic and topological layers by splitting the path in steps and then by adapting the geometric planning strategy to the local complexity of each step.
- Second, it integrates efficiently a human in the loop: real-time re-planning is computed based on operator's intent and motion control is shared by the user and the planner. Moreover, the user capabilities are used to overcome the automatic path planner weaknesses.

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