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AUTOMATED 3D-MOTION PLANNING FOR RAMPS AND STAIRS IN INTRA-LOGISTICS MATERIAL FLOW SIMULATIONS

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ABSTRACT

Commercial software of material flow simulations has the ability to layout the simulated models. Arranged equipment, such as conveyors or machines, includes the need to model and determine motion paths for moving objects like forklifts or automatically guided vehicles, so that the simulation framework is able to navigate all vehicles across those motion paths. After analyzing first scenarios, the user often carries out layout changes in the simulation model, e.g. moving, adding or deleting equipment. However, those changes cause time consuming, additional modeling of the motion paths for the user. Our motion planning algorithm reduces these changes by automatically determining the motion paths for moving objects, depending on an actual model layout without colliding with other objects. The algorithm works on the basis of the virtual scene's 3D-data used for the simulation model's visualization. We demonstrate the technique with a multi-floor building example.

1 INTRODUCTION

In the global competition "change simply happens" and therefore sustainable planning and flexible adaptation of all processes close to production poses a continuous challenge for companies. Innovative products as well as their corresponding manufacturing processes are to be reviewed at regular intervals in order to improve their efficiency and productivity. One well established method in the area of designing and safeguarding those production processes is the material flow simulation, where multiple scenarios can be modeled, simulated and evaluated before the factory's actual construction. During the last years, in this area, the trend increasingly followed the idea of a "digital factory" (VDI 2006), which covers among other disciplines the simulation and 3D-visualization of the designed processes (Dangelmaier and Laroque 2007). More often, in this research focus, multiple disciplines and methods close to the "basic" simulation, which are also used for the design of production or logistic processes, are connected and combined to simulation systems, in order to improve the gain of knowledge for a specific domain problem. In the area of the material flow simulation, these enhancements might cover modeling and simulation of multiple production systems in a supply chain (Gan et al. 2000; Holweg and Bicheno 2002) or the simulation of special logistic cells, e.g. in the construction industry (Rossmann et al. 2009).

Since the results of a special simulation scenario should lead to a higher understanding of the underlying system behavior, the generated experience of simulation results leads to improved system layouts and parameterizations of the simulation model as well as the designed production processes. Nowadays, in all commercial tools used for the material flow simulation, layout changes lead to a high workload of changes regarding the modeling and design of intra-logistic transport networks, e.g., used for the planning and dimensioning of forklift capacities and availabilities. Here, the automated generation of routing and motion paths for automated guided vehicles or forklifts reduces the modeling work by a simulation expert significantly, since an initial layout of possible paths is generated automatically via motion planning algorithms, based on the underlying layout data (Mahajan et al. 2005). Here again, for a specific problem, in this case the planning and safeguarding of intra-logistics, additional methods enrich the material flow simulation method, meaning the discrete event-based simulation, in order to improve the achieved simulation results in their level of detail, the gain of knowledge of the simulation expert, and the reduction of modeling effort.

Typically, today's design and production of new products doesn't lead to a "green field" design or a totally new layout of a new production plant, but existing processes have to be adapted and layouts within an existing facility are changed in order to be able to clear space for new production equipment or replace existing production lines. In some cases, this leads to complex plant structures, where goods are produced at different ground levels, connecting different halls or levels via ramps. In some cases production and storage are separated on different floor levels. Using existing solutions of such a motion planning algorithm (Mahajan et al. 2005), the simulation expert might be confronted with the weaknesses of the existing approaches, because the calculation of possible routes is based on a 2D-reduction of the factory layout and needs a high amount of calculation time. With such an approach a dynamic adoption of the plant layout, such as the forklift objects with or without transported goods or the modeling of pallet inventory in storage areas or loading platforms cannot be realized in real-time.

Here, the presented work enlarges the existing 2D approach to an automated 3D-motion planning algorithm, where these weaknesses can be solved. The automated calculation of motion paths over different floor levels is realized as well as the possibility of a dynamic enlargement of the underlying factory layout or the objects used for the intra-logistic transports. This allows this technique's use, not only during a specific scenario's simulation within a simulation experiment, but also within an interactive design process during modeling and parameterization. Forklift types can be changed as well as layout routes, regarding multiple floor levels or the integration of dynamic objects like trucks on "inbound" or "outbound" loading platforms.

Therefore, in a next step, the related work in this area within the material flow simulation as well as existing motion planning algorithm is covered in the next section. Afterwards, the main research goals of the presented solution are introduced as well as the basic method and algorithm, their application to an example factory and integration within a material flow simulation framework. The paper closes with an additional outlook on upcoming work.

2 RELATED WORK - MOTION PLANNING IN SIMULATION ENVIRONMENTS

In the modeling of moving objects, different modeling approaches are imaginable. Assuming a material flow, where goods enter at a specific point A and are carried by a forklift to a specific point B, where they will be processed. The modeling of connections between point A and B can be accomplished differently. In common simulation tools like Siemens' PlantSimulation (2010), Delmia's Quest (2010), Incontrol's Enterprise Dynamics (2010) etc., the transport object is using the direct way of transfer between these two points. If the distance between these points changes, their carrying time varies as well. Nevertheless, the underlying factory layout is not respected, e.g. walls or machines. In most tools, the element's motion between two points has to be modeled by the modeler using "non-flexible" paths, in order to be able to take the factory layout in the forklift's paths into account. The more complex the intended model, the more alternative paths for moving elements have to be modeled. Moreover, this approach fails, if the underlying layout changes due to planning advantages. The simulation expert has to change each possible motion path of a moving object based on the new layout.

In order to reduce the simulation expert's workload for modeling each path in a complex model, layout-based motion planning algorithms may automatically find motion paths for moving elements (La-

Valle 2006). Moreover, they are able to adopt the identified paths, if the layout changes. Fischer et al. (2005) and Mahajan et al. (2005) proposed a combined motion planning algorithm within a material flow simulation. The system is able to disburden the modeler from modeling motion paths for the transport objects. Autonomous vehicles like forklifts, etc. can be used within the simulation system, only by defining the start and end position in the underlying factory layout. The paths themselves are computed automatically by the system. Constrained objects like packets moving over a conveyer belt can be animated by defining an object's paths during the design of the building block "conveyor belt". The implemented system supports the motion of autonomous and constrained objects.

The motion planning algorithm consists of three steps as shown in Fischer et al. (2005). In the preprocessing and after changes in the layout of the scene, an object specific phase is performed to create a 2-dimensional outline from a 3-dimensional model. The second phase creates a scene specific graph representing possible paths for the moving objects. During runtime, this graph is used to search for a path from the current position of an object to its destination.

Recently Torchelsen et al. (2010) presented an approach for multi-agent path planning on arbitrary 3D surfaces. They use hierarchical computation of geodesic distances to define scalar fields whose gradient smoothly guides the objects across the surface. Their method can deal with meshes of arbitrary genus and curvature.

3 OVERVIEW

Our research goal and contribution of this paper is a methodology to reduce these time consuming, manual changes. We present a motion planning algorithm, which automatically determines the motion paths for moving objects, depending on the actual model layout without colliding with other objects of the virtual factory. The novel and particular feature of our method is, that it works, not only for a factory with one ground level, but moreover also for production or logistics facilities with multiple levels.

The designed motion planning (MP) algorithm works in two steps: In the first step, we process the 3D scene data of the simulation model and compute a data structure used for the automatic computation of possible motion paths. Each time the user modifies the simulation model, the processing of the static scene data is recomputed and updated, since the 3D layout might have also changed. This preprocessing step – called *MP scene processing* – is executed between modeling and simulation (see Figure 1). The MP scene processing and computation of motion paths is described in Section 4.

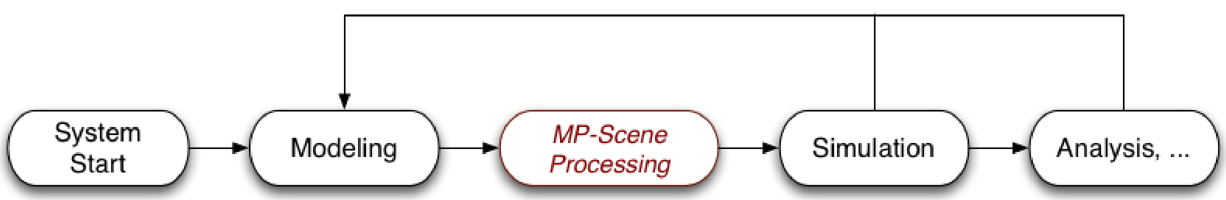

Figure 1: Workflow of modeling, simulation and analysis.

In the second step, the system computes motion paths for moving objects. They are computed on the fly during the simulation run, whenever the simulation needs to move objects, e.g. vehicles or avatars. Then the system dynamically computes a path for the object. The algorithm for this path computation is described in Section 4.3, its integration in the simulator, in Section 5. We evaluate our motion planning algorithm in Section 6.

We demonstrate the application of our motion planning algorithm by using an example of a multi-floor building. Our three-floor building is a facility, that produces some kind of goods (see **Figure 2**). Those goods are manufactured by robots, stored in a temporary storage, packed and bundled in a packing station. In the end, the finalized goods are delivered via trucks. We can show, that the algorithm handles 3D scenes of simulation models consisting of multiple floors, each connected with inclined ramps and stairs. Our algorithm automatically finds paths for the movement of vehicles across ramps and for the movement of persons' avatars across stairs. We report on:

- the movement of vehicles with start and end position on different floors,
- the collision prevention for overhanging objects,
- the computation of different kinds of driving surfaces used for the motion planning of paths,
- loading of trucks,
- and the computation of surfaces for moving packets on conveyor belts.

For demonstration of our motion planning algorithm in action with the simulation model shown in **Figure 2**, a movie is available (Fischer et al. 2010).

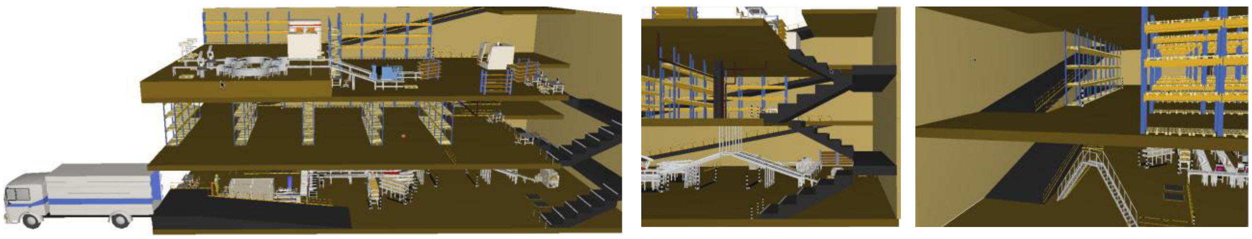

Figure 2: The left image shows the three levels of our multi-story building. The middle image shows a detailed view of the stairs and the right image shows a detailed view of two inclined ramps.

4 AN AUTOMATED 3D MOTION PLANNING FOR INTRA-LOGISTICS ENVIRONMENTS

In this section, details of the automatic MP scene processing algorithm are described. It starts with the automatic simplification of the complex layout data, since the exported CAD-data is typically too complex for further processing (see Figure 3). The idea is to convert the geometric objects from their continuous geometric representation into a set of voxels (Foley 1995), which at best approximates the continuous geometry (see Section 4.1). The second step is the computation of driving surfaces, which is a two-dimensional surface area within the 3D space. It includes all positions reachable for a specific moving vehicle (details in Section 4.2). The result of the MP scene processing is a data structure called *framed 3D rectangles*. It is used for the automatic computation of a motion planning query. For a motion planning query, the simulation framework only has to specify the start and destination position of the vehicles. The motion planning algorithm automatically finds a way, so that the simulation can use this data to compute transportation times (see Section 4.3).

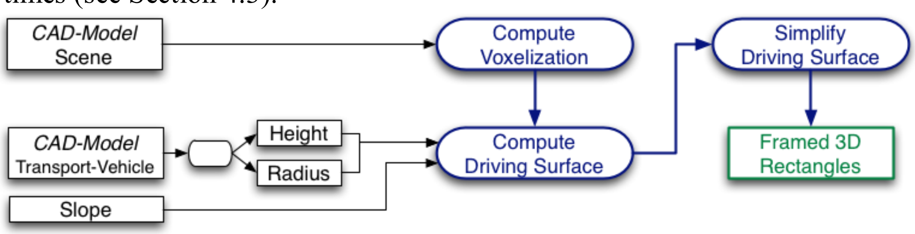

Figure 3: Structure of the MP scene processing

4.1 Simplification and Voxelization of the Scene Data

Our motion planning algorithm works on the simulation model's basic 3D-visualization data. In large simulation models such as production facilities, the exported 3D-layout data of the CAD-system is highly complex, so that it is impossible to render all objects in real-time. Nevertheless, the motion planning algorithm takes this large amount of data as the basic input for its computation. The complexity of the data