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Iterative path adaption (IPA): Predictive trajectory-estimation using static pathfinding algorithms

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Abstract

Nowadays the automotive industry is facing a growing demand for mass customization, while continually extending the product range in order to remain competitive. This trend leads to a higher diversity of the assembly processes and consequently to a rising complexity for production planning. Non-value-adding tasks are usually considered within the efficiency assessment of assembly lines. Since these are primarily walking tasks, it is becoming increasingly important to simulate realistic two-dimensional trajectories of assembly operators. However, most tools being currently used for that purpose are primary based on static path planners which do not consider dynamic obstacles. Consequently, simulated walk paths may significantly differ from their corresponding plan or even lead to collisions. Moreover, recent works present dynamic path planners generating trajectories while avoiding collisions in a dynamic environment. However, these approaches are not broadly available since their higher code complexity showed to be a major hurdle for commercial planning tools. In order to bridge the gap between widely spread static and primarily neglected time-dynamic planners, this paper contributes to a utilization of static path planners in dynamic environments. While maintaining the simplicity of static path planners, the novel heuristic method allows to model the time sensitive change of the surrounding regardless of the specific path planner implementations. The validity of the proposed approach has been proven using 5000 procedurally generated test scenarios. Moreover, the benefits of the proposed method were further outlined in an exemplary use case, representing a realistic production scenario.

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Keywords:Dynamic path planning; Factory planning; Intelligent agent; Artifical intelligence; Production planning; A*; Lazy theta*

1. Introduction

Trying to keep up with market demands for mass customization, automotive industry is currently producing an increasing number of model variants on mixed-model assembly lines [1]. This development induces a rising complexity for production planning departments, since assembly tasks within one assembly station may vary for each produced car. Therefore, tools enabling a realistic and efficient simulation of actual human work in an assembly line are becoming increasingly important. However, numerous traditional planning models tend to decreasingly reflect reality due to changing preconditions - especially for walk path of assembly operators (see [2]). Consequently, it is crucial to apply tailored planning models to ensure accurate assembly plans. Tools being currently used for walk paths simulation (i.e. [3]) rely on algorithms calculating a collision-free humanlike trajectory between a start and an end point. In particular, two-dimensional path planner such as A* [4] or Lazy Theta [5] are mainly utilized. These approaches, however, do not consider the movement of dynamic obstacles (i.e. cars), thus under-/overestimating walk paths length to a large extent (see [2]) - as depicted in Figure1.

Apart from the time-static path planner, literature presents various approaches (such as [6,7]) generating trajectories while explicitly avoiding collisions in a dynamic environment.

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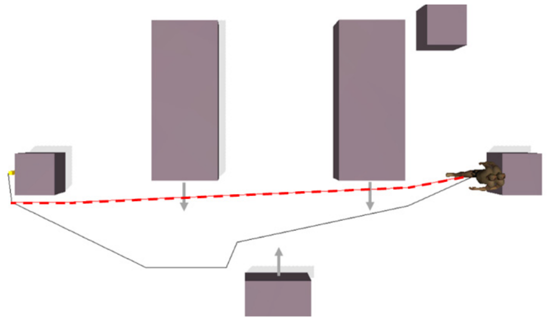

Fig. 1. A global collision free walk path computed in a dynamic scene using the IPA approach (black line) against a collision-afflicted path planned with static assumptions (red dotted line).

However, these approaches are not broadly available since their higher code complexity showed to be a major hurdle for commercial planning tools.

This paper presents a novel approach enabling static path planners to calculate collision-free trajectories while considering the movement of dynamic obstacles. The proposed system consists of an arbitrary static planning algorithm being wrapped with a novel, so-called "Iterative Path Adaption" (IPA) component. The latter introduces time as an additional dimension by successively updating the position estimations of dynamic obstacles. Therewith, any static path planner can be used out-of-the-box to generate collision free paths in dynamic two-dimensional environments.

The remainder of the paper is structured as follows: First, the state of the art in the context of two-dimensional path planning is reviewed. Second, a novel approach is described being able to determine a collision-free two-dimensional path in dynamic environments using static path planning algorithms. Consecutively, the applicability and technical performance of the proposed method is verified within a holistic evaluation. The paper concludes with an outlook on further optimization potentials.

2. State of the art

Path planning has been the subject of intense research and is applied in a vast variety of domains ranging from robotics [8] to crowd simulation [9], computer games [10] and production planning [3]. Independent of the specific use cases the problem of finding a collision free shortest path is oftentimes interpreted as a graph search problem. By discretizing the configuration space into connected nodes, the shortest paths can be computed using algorithms like Dijkstra [11] and A* [4]. Utilizing these approaches, the results are oftentimes unnatural due to the discretization of the space [1]. Using any angle path planning algorithms like Lazy Theta* [5], the paths can be computed without the restrictions of the grid structure in order to obtain more realistic and shorter paths. Literature proposes several approaches which can be further classified (see Gasparetto et al. [12]) into roadmap-techniques (see [13,14]), cell decomposition (i.e. [4][5,15]) and potential field based approaches [12]. For usage in high dimensional state spaces there are also probabilistic approaches applied, which cover probabilistic roadmaps [16] and rapidly exploring random trees [17]. In general most of the static path planners are easy to use, time efficient and the knowledge is widely spread. Nevertheless, those types of planners are not directly applicable to dynamic environments, since the environment is usually initialized once and never updated during the planning process. Consequently, these kind of planner algorithms are not suited for a dynamic car assembly shop floor.

Apart from the time-static path planner, previous works present a wide range of time-dynamic path planners which can be modeled with different approaches. The simplest way to handle path planning in dynamic environments is to treat dynamic as static objects (see [18]). Hence the computation of a path can be achieved with the above mentioned approaches. Using this simplified assumption, the dynamic behavior of the obstacles and agents are not explicitly considered, thus leading to unnatural walk paths which might not be feasible for an agent [19]. On the other hand, natural paths can be achieved using approaches such as [20] [6] [7] by explicitly considering the time and velocity of the obstacles. Using these dynamic planning methods, the dynamic shop floor environments can be modeled in principle. Nevertheless, the planners in this category are not broadly available and complex to setup. Additionally, aspects like line of sight checks which can improve the naturalness of paths (see [5]), are not covered within these algorithms. Utilizing the benefits of the static path planners, the proposed approach can cover these aspects in dynamic environments.

3. Approach

The main concept of the proposed approach is to reuse existing and well established algorithms for static path planning and encapsulating them in an additional component driven by an algorithm called Iterative Path Adaption (IPA). Independent of the specific implementations of the path planners, the proposed method allows a high-level incorporation of dynamic environments using an iterative repair function based on obstacle collision time estimations. Figure 2 shows the idea of the proposed method which can be interpreted as an additional component between the scene graph representation and the specific implementations of the path planning algorithms.

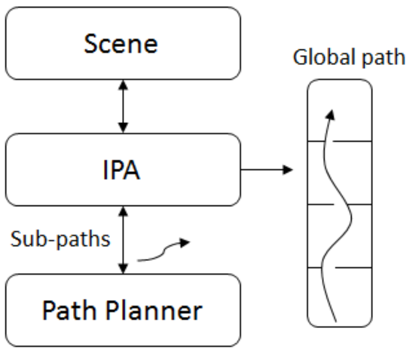

Fig. 2. Illustration of the principle idea of the IPA-algorithm. The algorithm represents an additional component between the static path planner implementation and the scene graph, enabling the static implementation to plan in dynamic environments.