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Path planning directed motion control of virtual humans in complex environments ☆

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ABSTRACT

Natural motion synthesis of virtual humans have been studied extensively, however, motion control of virtual characters actively responding to complex dynamic environments is still a challenging task in computer animation. It is a labor and cost intensive animator-driven work to create realistic human motions of character animations in a dynamically varying environment in movies, television and video games. To solve this problem, in this paper we propose a novel approach of motion synthesis that applies the optimal path planning to direct motion synthesis for generating realistic character motions in response to complex dynamic environment. In our framework, SIPP (Safe Interval Path Planning) search is implemented to plan a globally optimal path in complex dynamic environments. Three types of control anchors to motion synthesis are for the first time defined and extracted on the obtained planning path, including turning anchors, height anchors and time anchors. Directed by these control anchors, highly interactive motions of virtual character are synthesized by motion field which produces a wide variety of natural motions and has high control agility to handle complex dynamic environments. Experimental results have proven that our framework is capable of synthesizing motions of virtual humans naturally adapted to the complex dynamic environments which guarantee both the optimal path and the realistic motion simultaneously.

1. Introduction

Animating and controlling virtual humans realistically in complex dynamic environments are a crucial problem in computer animation, which depends on both the path virtual humans choose and the character motions synthesized. Many efforts have been made on the two aspects of path planning and motion synthesis respectively and great advancements have been achieved. However, it is still a challenging task in computer animation to create realistic and natural motions of character animation actively responding to complex dynamically varying environments.

To solve this problem, a novel comprehensive framework has been proposed in this paper which directs motion synthesis of virtual humans in complex dynamic environment by a global optimal path planned.

For path planning, SIPP algorithm [1] is used as path planner to find a globally optimal path from current

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location in a complex dynamic environment to another where virtual character want to go in the presence of dynamic obstacles, which adds time as an additional dimension into the search-space explored by the path planner to properly handle moving obstacles and introduces the concept of safe time intervals to greatly reduce the number of states that need to be searched. As the control information for directing motion synthesis of virtual character that drives virtual human follow the path planned naturally and realistically, three types of control anchors are defined, including turning anchors, height anchors and time anchors, and extracted from the path planned.

For motion synthesis, a popular traditional approach is motion graphs, which gains the motion that satisfies user demand by compressing connections among different pieces of motions in database and searching this graph. Although this is conceptually intuitive and broadly applicable, graph-based methods lack the adequate flexibility and controllability to synthesize agile reactivity of the animated character to the dynamically changing environment due to the sparse and finite states in the graph. In our framework, motion fields [2] approach is used as motion synthesizer, which organizes motion dataset into a high-dimensional generalization of a vector field of state space, then generates an animation by freely flowing through the motion field in response to interactive controls. Since each state in motion field has a set of candidate actions and Reinforcement Learning is adopted to find an action that leads to a desirable control, these enable real-time controlled highly responsive motion synthesis for motion field instead of waiting for pre-determined transition points for motion graph. So motion field is able to control character motion at arbitrary state in a continuous state space for motion synthesis, which allows highly agile motion controls with control anchors for adapting to dynamically varying environment and guaranteeing the synthesized character motion well-fitting to the global optimal path planned.

2. Related works

Our work is mainly related to two fields: path planning and motion synthesis for character animations. Many previous works have been done in both fields.

Path planning approaches usually can be divided into undirected and directed. Undirected approach seeks to go blindly through a maze, which has two main approaches including Depth-first search and Breadth-first search [3]. These approaches expand searched nodes without directing, so that they may be unable to find a way out. Some measures of assessing have been introduced to solve this problem, which introduce directed approach. Dijkstra's algorithm [4] and A⁎ algorithm [5,6] estimate the cost of moving by measuring the distance between the nodes to direct which node should be expanded. Although this approach can find a path with the lowest cost, the path is not always the most efficient solution [7]. In addition, these approaches can't solve the cases with dynamic obstacles due to pre-processing computation, where the agent may wait for all dynamic obstacles passing or collide with dynamic obstacles. SIPP [1] is proposed to plan an optimal path in complex dynamic environments with moving obstacles by introducing the concepts of the safe interval and the earliest arrival time, which is also implemented as the path planner in our work to handle the moving obstacle in complex dynamic environment.

Over past decade, creating character animations from raw mocap data have been studied extensively in research and industry, which may offer many advantages over traditional computer animation. Since motion capture system is not cheap and already captured motion data don't always reflect our needs, it is necessary to reuse and edit the existing motion capture data for synthesizing new required motion rather than capturing new motion whenever needed. To improve reusability of motion capture data for reusing and editing have become a challenging problem in mocap data-driven motion synthesis.

Motion graphs [8–10] were proposed simultaneously by several groups in 2002 and have been emerged as a primary technique for automatic synthesis of character motions at runtime, which employ the bag-of-clips data structures and generate motion by concatenating short motion clips to accomplish the desired task. In the subsequent years, many approaches have been developed to extend and augment motion graphs. Shin et al. [11] proposed parameterized motion graphs; Safonova et al. [12] applied interpolated motion graph and optimal search; Ikemoto et al. [13] adopted multi-way motion blending to generate transitions quickly; Ren et al. [14] proposed an optimization-based graph that combines continuous constrained optimization with graph-based motion synthesis; Zhao et al. [15,16] searched motion graph to extract a minimum size sub-graph and build interpolated segments of motion with same contact pattern to keep best transition. So the motion synthesized is constrained by the mocap dataset that the graph is built from, and the structural control of motion graph lacks the controllability to synthesize agile response to a dynamically changing interactive environment so that synthesized motions of virtual humans can't respond quickly to changes of walking direction or unexpected disturbances adapting to the complex and dynamic environment.

Some researchers have been conducted on remedying the drawback of space discontinuous in motion graph. Wang et al. [17] introduce Gaussian process dynamical models (GPDMs) for learning models of human pose and motion from high-dimensional motion capture data, and high-quality motions can be synthesized from the learned model. Ye and Liu [18] described an optimal feedback controller for motion tracking that allows for on-the-fly re-planning of long term goals and final completion time. This technique is able to synthetize motion from arbitrary frame and the controller can handle perturbations and changes in the environments, but it implements only an approximation of the optimality condition for the synthesized motion of virtual character at current state. Instead of modeling the most possible single motion, motion field approach [2] modeled a set of candidate motions at each motion state and selected a motion by employing an optimal control framework based on Reinforcement Learning, which freed the character from simply replaying the