Planning motions for animated characters

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Abstract. Human or more generally articulated figure animations have been seen in a variety of application fields including advertising, entertainment, education, and simulation. The primary research goal now to further the animation is providing a system which allows animators to easily and interactively design and get desired movements. We present a method for animating human characters, especially dedicated to walk planning in virtual environments. Our method is integrated in a probabilistic roadmap method scheme. The success of our approach is demonstrated through several examples.

Keywords: Motion planning, autonomous characters, probabilistic roadmaps.

1 Introduction

A typical motion planning problem asks for computing a collision-free motion between two given placements of a given robot in an environment populated with obstacles. The problem is typically solved in the *configuration space* $\mathcal{C}$.

Over the years many different approaches to solve this problem have been suggested. The probabilistic roadmap planner (PRM) is a relatively new approach to motion planning [1]. It turns out to be very efficient, easy to implement, and applicable for many different types of problems.

Motion planning has application in many other areas, such as assembly planning, design for manufacturing, virtual prototyping, computer animation, medical surgery simulation, and computational biology. As stressed by Latombe [2], non-robotics applications (e.g. graphics animation, surgical planning and computational biology) are growing in importance and are likely to shape future motion planning research at least as much as robotics.

This work presents a solution for the planning human walk through virtual environments. The solution is based on probabilistic roadmap motion planning techniques combined with a character motion controller.

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2 Related work

An early effort at addressing the motion planning problem in computer graphics was proposed in [3]. In [4] a path planner is developed for several cooperating arms to manipulate a movable object between two configurations in the context of computer animation.

Later, J. Kuffner [5] proposed a new technique for computing collision-free navigation motions from task-level commands for animated human characters in interactive virtual environments. His approach is efficient and consists in splitting the problem in two parts: the digital actor is bounded by a cylinder to compute a collision-free trajectory and a motion controller is used to animate the actor along the planned trajectory.

Foskey et al [6] proposed a hybrid motion planning algorithm for rigid bodies translating and rotating in a 3D workspace. The method generates a Voronoï roadmap in the workspace and combine it with "bridges" computed by randomized path planning with Voronoï-based sampling.

A practical motion planner for humanoids and animated human figures was proposed in [7]. In this work, the workspace is modelled as a multi layered grid and several types of digital actors bounding boxes are considered according to predefined locomotion behaviours (walking, crawling,...). Once a path has been found in the grid, the cyclic motion patterns are used to animate a trajectory throughout the path. Finally, the animation is modified using dynamic filters to make it consistent.

A similar approach that combines path planner and motion controller has been proposed in [8]. A solution to the locomotion planning problem for digital actors was recently proposed in [9]. The solution is based both on probabilistic motion planning and on motion capture blending and warping.

3 Model and motion data

We know that many dynamics models were designed in the nineties in order to synthesize human figure motion, but it is unlikely that dynamics simulation will solve all animation problem. Researchers have thus turned to other kinds of approaches. The recent progress in motion capture techniques makes it possible to directly use human motion data. Animating very complex model such as virtual human is usually done by extracting a simpler representation of the model, a "skeleton", that is an articulated figure made of rigid links connected by hinges. We first prepare a skeleton model represented with a hierarchical structure of rotational joints. The number of joints of the model and the degrees of freedom depend largely on the desired reality or quality. In this paper we employ a relatively simple model with 52 degrees of freedom (dofs) detailed on Fig. 1. Motion capture data depend on the model and represent the evolution of the configuration through the time, in several cases: walks, turns, runs, etc.

The structure of the character is modeled in two levels. Pelvis and legs are used for the locomotion, all the 18 dofs are said to be active dofs. The 34 other

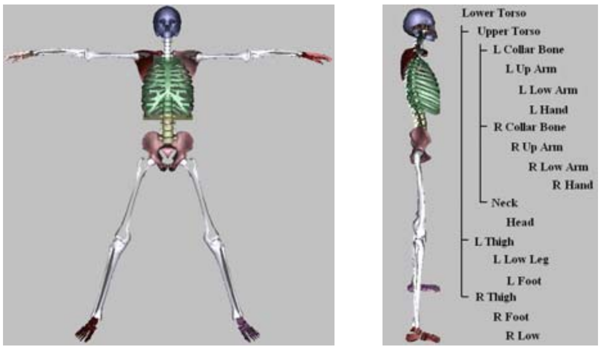

Fig. 1. Computer model of the character.

ones are said to be reactive dofs, they deal with the control of the arms and the spine [9]. The pelvis is the root of five kinematics chains modelling respectively the arms, the legs and the spine. Root's trajectory problem concerns only $[x, y, z, \theta, \phi, \psi]$ parameter's evolution. The inputs are two collision-free configurations of the character in the configuration space. The local navigation of the character is modeled with a third degree Bezier curve.

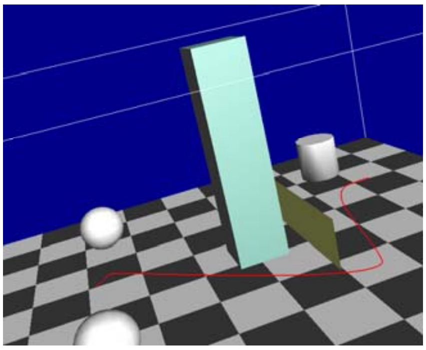

Fig. 2. A path made of few Bezier curves.

Bounding the character's geometry by a cylinder allows motion planning for navigation to be reduced to planning collision-free trajectories for this cylinder in 3D.

Motion capture yields an unstructured representation, a sequence of sampled positions for each degree of freedom, or through pre-processing using inverse kinematics, sequences of joint angle values. Editing this kind of iconic description poses a problem analogous to that of editing a bitmapped image or a sampled hand-drawn curve. We call the motion warping all techniques that take well-known trajectories and modify them in order to change the motion. Witkin and

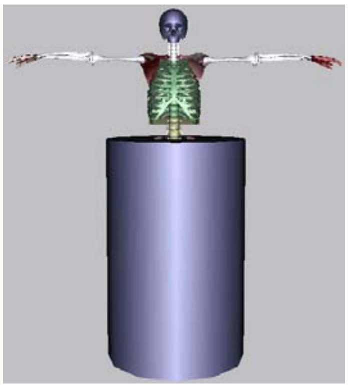

Fig. 3. The character's geometry is bounded by an appropriate cylinder.

Popović [10] modified a reference trajectory $\theta_i(t)$ (where i represents the i^{th} parameter of the system) by interactively tuning the position of selected key-frames and by scaling and shifting $\theta_i(t)$.

$$\begin{array}{c}\forall i, \theta'_i(t) = a(t)\theta_i(t) + b(t)\\ t = g(t')\end{array} \tag{1}$$

Function $a(t)$ is used to scale the signal and $b(t)$ is used to change the center of scaling of a. The deformation from time t to t' is a constrained interpolation based on Cardinal splines. Thus, the resulting sequence satisfies the constraints of new key-frames with respect to the pattern of the initial motion. Moreover, blending of several motion can be obtained by weighted sums.

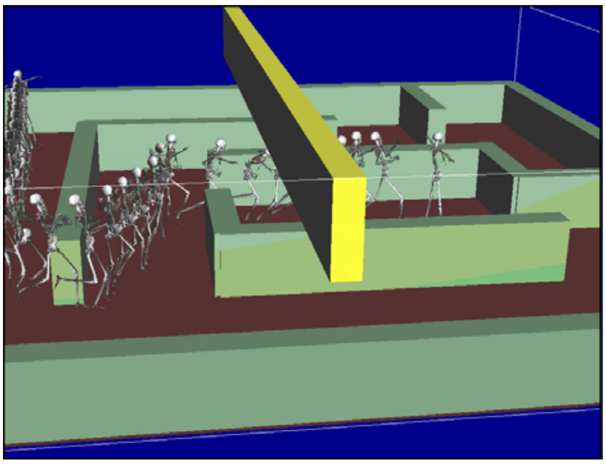

Fig. 4. The result of the warping module implemented.

4 RMP3D architecture

RMP3D is composed of diverse modules associated with functionalities such as the modeling of the mechanical systems (geometric modeling, steering methods), geometrical tools (collision detection, distance calculation), motion planning, and a graphic interface that allows to define the problems, call the algorithms, and to display the produced results. Fig. 5 shows the structure of the motion planning software RMP3D.

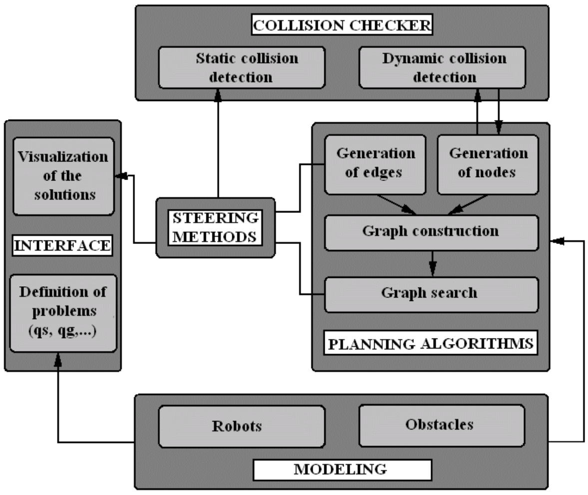

Fig. 5. Architecture of RMP3D.

- the modeling module enables the user to describe mechanical systems and environments.
- the geometric tools for the collision detection algorithms.
- the steering methods allows to compute local paths satisfying the kinematic constraints of the mechanical systems.
- the planning algorithms module contains many procedures based on randomized techniques such as PRM, Lazy PRM, Visibility PRM.

The following steering methods are actually integrated within RMP3D:

- **Linear** computes a straight line segment between two configurations, this method works for any holonomic system.
- **Nonholonomic** computes smooth paths for both car models, Reeds & Shepp and Dubins.

Other methods could be easily integrated into this library.

The planning module integrates three of the randomized techniques proposed recently. These techniques are based on the probabilistic roadmap methods that first construct a roadmap connecting collision-free configurations picked at random, and then use this roadmap to answer multiple or single queries.

- Basic-PRM is based on the basic PRM scheme [1]. The key idea of this scheme is to randomly distribute a set of nodes in $\mathcal{C}$ and then connect these nodes using a simple local planner (or a steering method), to form a graph (or a tree) known as a roadmap.
- Gaussian-PRM is meant to add more samples near obstacles [11]. The idea is to take two random samples, where the distance between the sampless is chosen according to a Gaussian distribution. Only if one of the samples lies in the $\mathcal{C}_{free}$ and the other lies in $\mathcal{C}_{obstacles}$ do we add the free sample. It has been shown that this leads to a favorable sample distribution.
- Lazy-PRM [12], the idea is not to test whether the paths are collision free unless they are really needed. The goal of this variant is to minimize the number of collision checks. The rational behind this is that for most paths we only need to consider a small part of the graph before a solution is found.

The collision checker integrated is PQP[1] for determining whether a given path is collision-free or not (this is performed by multiple calls to the interference detection algorithm). PQP is a library for performing three types of proximity queries on a pair of geometric models composed of triangles.

5 Planning algorithm

Navigation in unstructured environments entails some particular challenges. Global and local solutions can be strongly linked; the choice of a particular route towards a goal is predicated on the route being viable every step along the way. Planning algorithms for such problems thus require the ability to plan motions across both small and large time scales. A second challenge is that creating motions involves both discrete and continuous decisions. An example of a discrete decision is that of deciding whether to step on or over an obstacle, or simply deciding which of a finite set of possible hand-holds to use. Once the contact points of a character with the environment have been chosen, the remaining decisions shaping the motion can be regarded as being continuous in nature. This particular environment requires the alternating use of several modes of locomotion in order to navigate towards the goal.

Given start and goal positions in a virtual environment, our objective is to find a sequence of motions of a human character to move from the start and to the goal. Conventional motion planning techniques in robotics typically generate very efficient mechanical movements rather that lifelike natural-looking motions desired in computer animation applications. On the other hand, motion editing techniques in computer graphics are not equipped with a high-level planning

[1] A collision detection package from University of North Carolina at Chapel Hill

capability to yield a desired motion. To rapidly plan convincing motions of the human-like character with high-level directives, we use a novel combination of probabilistic path planning and motion capture editing techniques.

Our scheme consists of the following three steps: roadmap construction, roadmap search, and motion generation.

1. **Roadmap construction**: Given a virtual environment, we randomly sample valid configurations of the cylinder bounding the lower part of the character. The roadmap can be modeled as a directed graph whose nodes represent valid samples of the configuration space. A pair of nodes are connected by and edge if the character can move from one node to the other with a prescribed motion while preserving its lifelikeness.
2. **Roadmap search**: Once the roadmap reflects the connectivity of $\mathcal{C}_{free}$ it can be used to answer motion planning queries. Then a path in the roadmap is found which corresponds to a motion of the character. The first path is optimised by a classical dichotomy technique. The output of this step is a sequence of continuous composition of Bezier curves.
3. **Motion generation**: Simply computing a collision-free path in the environment is not enough to produce realistic animation. This step transforms the obtained path into a discrete set of time stamped positions for the character along the trajectory, respecting some criteria of velocities and accelerations. Finally, a locomotion control procedure transforms a set of time parametrised positions into a walk sequence, for example. It is based on a motion capture blending technique [9].

Although the motion planning and following concept generally applies to many types of characters and motions, we will concentrate on generating walking or running motions for a human-like character. We would like the character's motion to be smooth and continuous, natural-looking, and follow the computed path as closely as possible. Though many kinds of path following techniques could potentially be used [13].

6 Implementation and experimental results

The motion planning platform RMP3D was implemented on an Intel © Pentium IV processor-based PC running at 2.6 GHz with 1Gb RAM, using Builder C++ and OpenGL.

During an interactive session, the user can choose the inputs (initial and final configurations), and the motion planner will calculate a collision-free path (if one exists) in approximately some seconds (this time depends on the used planner and the geometry of the environment). The path is then smoothed by means of Bezier curves and sent directly to the controller, and the character will immediately begin follow the new path.

Our first experiments is for planning a walking motion. Figures 6 and 7 show an example of the construction of an animation.

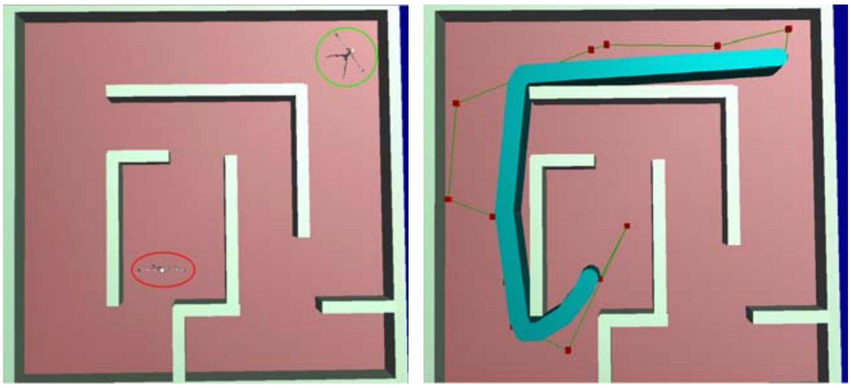

Fig. 6. Start and goal configurations (inputs) and root's trajectory.

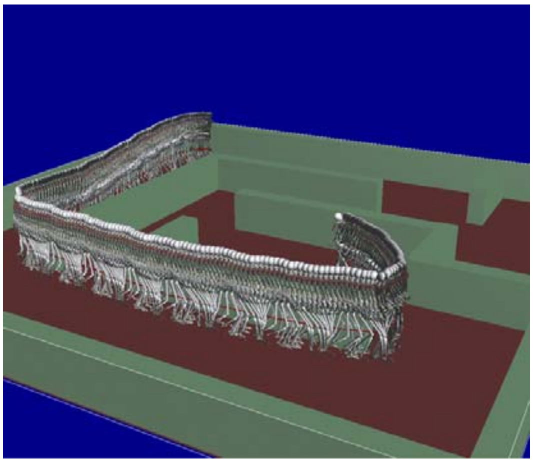

Fig. 7. Walk cycle introduction.

Good performance has been achieved, even on complex scenes with multiple characters and environments composed of more than 191, 410 triangle primitives. A result of complete trajectory (composition of several local paths) is presented on Fig. 8. One can notice several specificities in this result: the model strictly respects the initial and final configurations required (the initial and final phases of walk are thus influenced by these data).

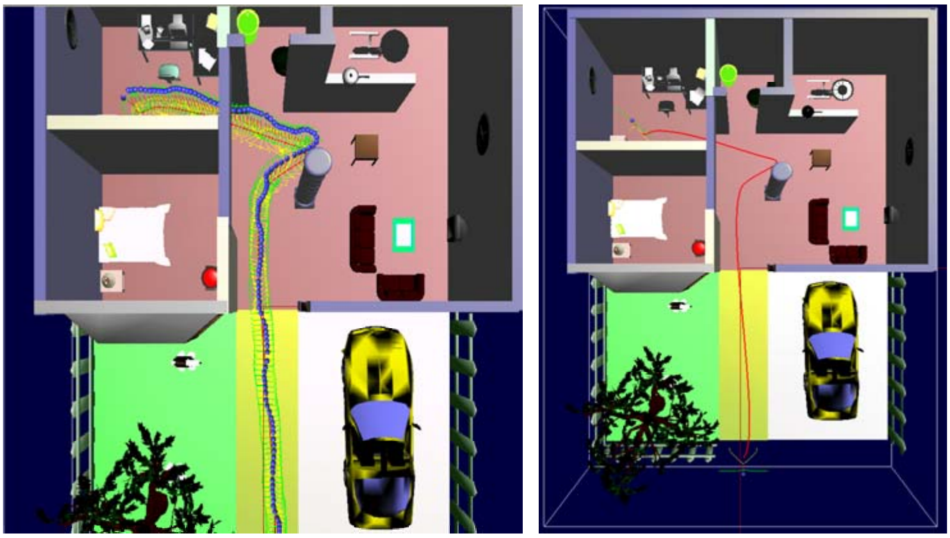

Fig. 8. A complete walk planning through a complex environment (191, 410 triangles).

We have presented a human walk planning method associating randomized motion planning and motion capture editing techniques. Our first results obtained are very promising.

7 Conclusions and future work

Animation of human walking is a crucial problem in computer graphics: many synthetic scenes involve virtual humans, form special effects in the film industry to virtual reality and video games. Synthesizing realistic human motion is a challenge. The study of walking motions has been generated much interest in other fields such as biomechanics and robotics. The interest for this area has never decreased in the computer animation community, even though the task is not easy, since techniques based on kinematics, dynamics, biomechanics, robotics and even signal processing may be required.

This work presented a method for animating human characters. This approach satisfies some computer graphics criteria such as realistic results, collision-free motion in cluttered environments and low response time. The approach has been implemented in our RMP3D architecture and successfully demonstrated on several examples. The combination of randomized motion planning techniques and motion capture editing techniques offer promising results [9].

RMP3D uses Basic-PRM, Gaussian-PRM or Lazy-PRM techniques that captures the configuration space connectivity into a roadmap. Through the examples we have demonstrated that our approach works well. The computing time vary according to the selected scheme of planning.

Although some promising results are shown in its present form, the algorithm could be improved in a number of important ways. We are interested in investigating reactive planning methods to deal with dynamic environments. The generation of collision-free motions for two or more characters, is another objective to the future and also the cooperation between virtual characters handling bulky objects, etc.

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