Free Fall Motion Synthesis

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Abstract

We present in this paper a framework that generates free fall motions for the object within a still fluid. We introduce a new motion synthesis approach where six characteristic motion prototypes of free fall are defined and synthesized, and then the motion trajectory is specified form free fall motion graph. We automatically create motion sequences using trajectory search tree and pre-computed trajectory database. The proposed approach can produce realistic and controllable free fall motion that could be applied in many different applications, including virtual reality, game and other entertainment productions.

CR Categories: I.2.7 [Artificial Intelligence]: Problem Solving, Control Methods and Search—Graph and tree search strategies; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Animation;

Keywords: physically based animation, motion prototypes, free fall

1 Introduction

It is difficult to simulate the common and spectacular free falling motions around us in computer graphics (e.g., paper, leaves, and snowflakes within air). Our main purpose is to extract the physical rules behind the phenomena and archive realistic simulation results.

Most motion generations of free fall are example-based approaches. They synthesized the motion trajectories from captured video, simple fluid simulation, commercial 3D animation software, or sketch example. All these approaches ignored the nature of free fall and considered the free fall as complex and unpredictable process using complete stochastic model or simple particle representation in flow. As the another approach, physicist recently focused on the unsteady dynamic of free falling through thousands of experiments and this remains a significant challenge [Razavi 2010].

In this work, we propose new approach combining both experimental and theoretical results. About the free fall in computer graphics, our primary focus examines all the motion types of light-weight objects to create reliable and natural motion paths by using motion planning in real time environment.

2 Motion Generation

Our method (Figure 1) uses the initial conditions and physical parameters of a light-weight object with 6 degree of freedoms as inputs, including the physical characteristics of the object and fluid wherein released (release height, mass, etc.). We transform the parameters to two important non-dimensional numbers Re and I^*, and then lookup the phase diagram (Figure 1) of free fall to query the main motion prototype which is the stable status for the falling object.

After the main motion prototype is decided, we first determine the motion types based on motion groups. For all motion types of the decided motion type, our probability model is adopted to choose the actual motion paths. In our work, the motion trajectory is constructed from six motion sequences of motion prototypes. The free fall motion graphs are used to synthesize the trajectories from the designated motion segments. The final free fall motions are synthesized after the initial trajectories are determined through optimization.

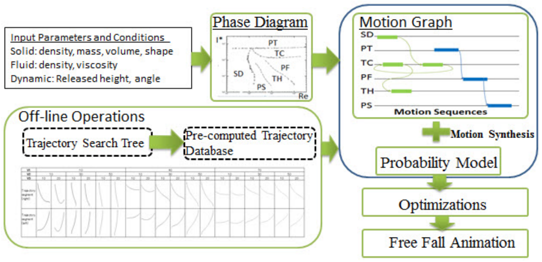


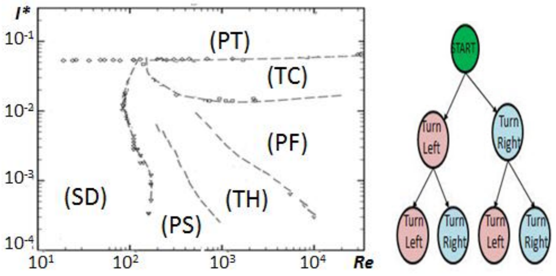
Figure 1: *Overview of motion generation*

2.1 Motion Prototypes Definition and Synthesis

For the dynamic of free fall motion, there are two critical dimensionless quantities: the Reynolds number Re and the dimensionless moment of inertia I^*.

$$Re = \frac{a\sqrt{gb(\frac{\rho_s}{\rho_f} - 1)}}{\nu}, I^* = \frac{\rho_s b(a^2 + b^2)}{2\rho_f a^3}$$

Where a and b are the length and width of the cross section of object; ρ_s and ρ_f are the densities of the object and fluid; g the gravity acceleration and ν the kinematic viscosity of the fluid. Based on numerous experiments [Zhong et al. 2011], six basic motion prototypes have been identified in the phase diagram (Figure 2(a)): Steady Decent (SD), Periodic Fluttering (PF), Transitional Chaotic motion (TC), Periodic Tumbling (PT), Transitional Helix motion (TH) and Periodic Spiral motion (PS), which are illustrated in Figure 3 (top). For PF, PT and TC motions, we use the trajectory search tree to present the motion structure as the motion becomes sensitive when the object reaches turning points represented as nodes in the



(a) (b)

Figure 2: *(a) Phase diagram of free fall motion, six types of motion prototypes in different regions. (b) Trajectory search tree*

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Figure 2(b). Consistent with the experiments in the work [Zhong et al. 2011], the trajectory of TH is presented as a helix curve with 8 petals rhodonea curve viewed in the XY plane which is perpendicular to the falling direction and PS is a spiral curve, all of which are formulated in uniform harmonic functions.

We achieved the segments and orientations by solving the ordinary differential equations in the 2D force model of free fall by standard fourth-order Runge-Kutta method. The precomputed trajectory database is built after clustering the segments by K-means clustering algorithm. The synthesized trajectories of motion prototypes are shown in Figure 3 (bottom).

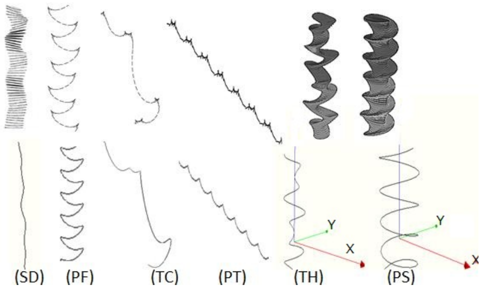


Figure 3: *Experimentally measured trajectories of motion prototypes (top) and our synthesized results (bottom)*

2.2 Motion Groups

Based on thousands of experiments in [Razavi 2010], we propose the rule for connecting motion prototypes and the motion selection based on our probability model. The seven motion groups(Figure 4) from experimental data have correspondence to the phase diagram (Figure 1). The free fall motions become sensitive while increasing Re but decreasing I^*. As previous experiments use in quasi-2D setups, we only get the main motion prototypes by looking up phase diagram using Re and I^*. Then the insensitive motion prototypes are included in the motion group by the order of motion prototypes in Figure 4. We select the motion by probabilities of each motion prototypes from experimental data, which are (0.1, 0.38, 0.1, 0.17, 0.11, 0.14) in the given order.

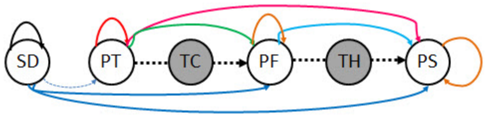


Figure 4: *Seven motion groups in different coloured lines*

2.3 Motion Synthesis using Motion Graph

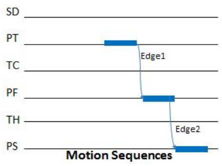


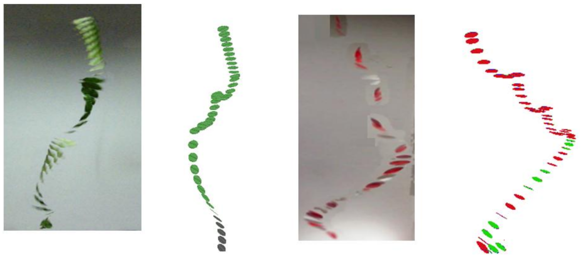
Figure 5: *Free fall motion graph*

The special free fall motion graph (Figure 5) is based on the approach of motion graph in [Kovar, et al. 2002], where every frame in these motion sequences can be a node in the motion graph; the edge between nodes is a transition splice in sequences. We search the graph only in one-way from top to down as the order mentioned in section 2.2. Consequently, it is impossible that free fall motions become tumbling after spirally falling as an example.

3 Experimental Results

Our approach is suitable for any types of light-weight objects in the different still fluid flow. Figure 6(a) shows an example of a Japanese one yen coin free falling within water. A normal periodical fluttering motion is expected from phase diagram according to the calculated Re and I^*. In Figure 6(b), the quasi-elliptical leaf starts from steady falling, tumbling and then falls in helix motion. The free fall motion of a long elliptical paper in Figure 6(c) involves tumbling and spiral motions. All of these motion sequences are made by motion prototypes and queried from pre-computed trajectory database. These are implemented in C++ on an Intel Core i7 CPU 1.73 GHz and 4.0 GB RAM in real time (around 50fps).

(a) Coin free falling within water



(b) Leaf free falling within air (c) Paper free falling within air

Figure 6: *Comparison ground truth (left) with our simulation results (right)*

4 Conclusions

This paper presents a framework for generating free fall motion by data-driven motion synthesis and precomputed trajectory database. Our work is the first research about the physical details of free fall motion and proposed an efficient motion synthesis approach to achieve realistic and predictable free fall simulation.

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