

# **Dynamic Simulation of Human Diving and Splashing Fluids**

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## **SUMMARY**

Physically based simulation of 10 meter platform dives from the initial stance of a human diver to the splash at water entry. A dynamic model and control system are used to generate the motion of the diver. The dynamics of incompressible fluids and particle systems are combined to produce the splash.

## INTRODUCTION

Humans are adept at perceiving the subtle details of human motion. If we are to generate synthetic humans for computer animation and virtual environments, then we must not only generate images that appear realistic, but we must also generate natural looking motion for the actor and for the objects in the environment. One potential source of realistic motion is dynamic simulation coupled with control systems. In order to use simulation as a source of motion we must have a physically realistic kinematic and dynamic model of the actor and the environment. To generate the motion of robots, animals and humans, we also need control systems that can perform the required task in a way that appears natural. We present work that addresses some of the issues in using simulation to generate natural looking motion.

## BACKGROUND

Research in three fields is relevant to the problem of simulating human divers: robotics, computer graphics, and biomechanics. The diver in this presentation is based on control algorithms for robot locomotion developed by Raibert and Hodgins[11]. From the biomechanics literature, Frohlich[5] and Yeadon[14] provide detailed analysis of human motion in flight, and Eaves[3] provides insight on the mechanics of diving. In the computer graphics community, Badler[1] has developed a system to model kinematics and dynamics of humans, and Magnenat-Thalmann and Thalmann[9] have explored methods for producing realistic animations and images of humans.

The dynamic simulation of fluid bodies has been addressed in several ways. One of the most accurate is to solve the 3D Navier-Stokes equations that describe the fluid body[7]. This approach is well suited for simulations requiring a high level of detail, but has a high computational cost. Particle systems have been used to model waterfalls[13]. Fournier and Reeves[4] and Peachey[10] have implemented other techniques that model the movement of explicit waves over the surface of a fluid. Kass and Miller[6] used shallow water equations for real-time simulation of water under conditions that did not involve splashing.

## DIVER SIMULATION AND CONTROL SYSTEM

We have developed a simulation of a human diver with 38 controlled degrees of freedom. The human model can perform a number of 10 meter platform dives. The dives showcased in this presentation are an inward 1-1/2 somersault pike, a reverse 3-1/2 somersault tuck, and a backward 1-1/2 somersault with a half twist. The dynamic model of the diver consists of 15 rigid bodies connected by rotary joints. The dynamic properties of the rigid bodies were calculated using densities for each body part measured from cadavers[2], and algorithms for computing moments of inertia from polygonal

objects[8]. The equations of motion were generated using a commercially available package, that uses a variant of Kane's method with a symbolic simplification phase[12].

The control system for the diver is hierarchical. The low-level control is provided by proportional-derivative servos that move the joints towards their desired values. Balance on the diving board is provided by a controller at the ankle that computes the angle for the ankle that would place the body's center of mass over the feet. This angle serves as a desired angle for the low-level PD control. High-level control for the dive is provided by a state machine that alters the desired configuration of the diver. Five states are used in the 10m platform dives: Compression, Decompression, Flight-Phase 1, Flight-Phase 2, and Entry. The high-level control alters not only the desired values for the joints but also the gain on the low level PD servos. For example, the gains required for the compression phase of the dive are higher than the gains required for the flight phase. The gains and set points for the controllers were tuned by hand to ensure that the diver performs the dive and enters the water vertically.

### **SIMULATION OF SPLASHING FLUIDS**

The water in the pool is modeled as a deformable fluid body discretized into vertical columns. Similar to the formulation used by Kass and Miller[6], we model the flow between these columns using a network of virtual pipes. Flow within the pipes is simulated using non-turbulent flow equations driven by forces arising from hydrostatic and external pressure differentials.

A deformable mesh is mapped onto the surface of the fluid to model surface effects. The forces resulting from impacts to this surface are propagated to the volume model as pressure changes. As the net upward velocity of a column increases particles are spawned to model the spray from the splash. The initial positions of the particles are distributed over the area of the surface mesh that corresponds to the rising column. Initial velocities are determined by summing the velocity vectors of the fluid flowing in the pipes under the surface and the upward velocity of the column. The size of each particle is proportional to the force acting upward in the column.

To conserve the total volume in the system, the volume of a particle is removed from the column that spawned it. Once spawned, particles move under the influence of gravity and do not interact with each other. Particles are destroyed when they fall below the surface and the particle volume is added to the corresponding column.

These techniques allows us to model the effects of objects impacting the fluid as well as the subsequent waves formed by the disturbance. The water simulation used for the dives used 58,000 control nodes isotropically distributed over a 256 square meter area. The number of particles used for the splashes varies with time, reaching a maximum of about 20,000.

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