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A Simulation Framework for Combustion, Burning, and Decomposition of Solid Objects

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Abstract

We present a simulation framework to integrate several aspects of the combustion and burning process in a unified and modular manner.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Physically Based Modeling;

1. Introduction

Recent models within the computer graphics community [MBR*02, NFJ02, FOA03] have begun to simulate fire based on fluid simulations. While their models implement some fire related phenomena, there have not been any offering a framework that addresses all the major fire-related phenomena. In this work, we present a framework combining different modules to simulate many aspects of the burning process in a unified simulation. It consists of two main modules, which are a fire/flame simulation and a solid object simulation. Each of these is composed of several submodules dealing with different phenomena. The two simulations are coupled together by pyrolysis.

2. Fire Simulation

The fire module is responsible for air motion, gas distribution, and heat generation. It models the combustion process, which generates heat and drives the air motion.

- It should track distribution of different gases.
- Motion of the hot air needs to be modeled, including tracking which parts of the simulation domain are covered by objects.
- The combustion process, which consumes fuel gas and generates smoke and heat, should be modeled.
- Heat transfer should be modeled explicitly.

In our simple flame model [MK03], we transport the fuel and exhaust gases with the motion of the air, creating a dynamic 3-gas system. We assume there is only one moving gas, which is inviscid, incompressible, and constant density. The fluid motion [FSJ01] is applied to advect three quantities: fuel gas, exhaust gas, and heat. We simulate the combustion process by combining fuel and oxidizer in a cell, creating additional exhaust gas and heat in the cell. Solid objects in pyrolysis provide fuel gas to the module, similar to any generic fuel source. Heat transfer is modeled in three stages: heat transfer in the air, heat transfer between the air and the solid, and heat conduction within solids. This three-stage heat transfer model enables us to treat solids with varying thermal properties. Heat convection in air is handled using semi-Lagrangian advection, which simulates moving air currents carrying heat. Radiative heat transfer is approximated as a diffusion process using implicit integration.

3. Solid Objects

The solid objects module consists of heat transfer, object decomposition, and a rigid body solver.

- Information must be provided about which parts of the scene are occupied by the objects.
- Heat triggers pyrolysis, which generates fuel gas.
- During pyrolysis, solid objects deform under decomposition.
- Objects should undergo rigid body motion.

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Figure 1: *Different oriented burning matches*

Our model for decomposition is the first model in CG literature for defining decomposing objects under combustion. Two complementary representations are used. First representation, solid fuel amount, represents how much solid fuel we still have available at the cell. A second representation, the distance field, represents the decomposed solid including both the solid fuel left and the residue (ashes) in that cell. Although the two representations are equivalent at the start of the simulation, we intentionally allow them to diverge during the simulation. The decomposition of the burning solid is modeled as a moving boundary in the distance field, and is defined in the direction of the fuel consumption gradient with rate of solid fuel consumption. We apply level set methods [OF02] on the distance field representation. As objects decompose, thin or disconnected pieces can be created. We use a set of particles placed at the vertices of the visualization polygons, and interpolation on the distance field grid of the other objects directly gives us the distance to the boundary, letting us know whether the objects have collided.

4. Module Interface and Execution

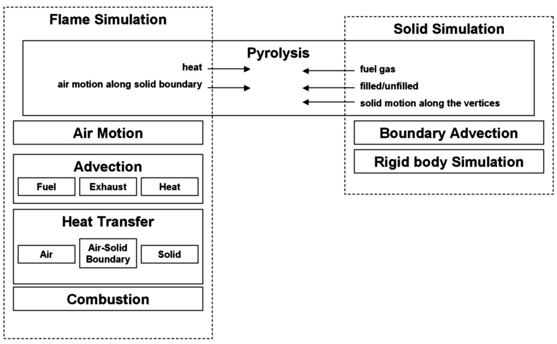

Figure 2: *Integration between simulation modules*

The two simulations described above are joined through the pyrolysis step. A pyrolysis time step begins transferring filled/unfilled information from the solids into the flame module. The air-solid boundary is traced and the heat differentials are used to exchange heat. The next step is transferring forces in the fluid motion field. Solid objects are simulated within their own space. The pyrolysis cells convert solid fuel into fuel gas as a function of heat, and it is passed to the flame simulator. The fuel conversion differential drives the object decomposition process. Decomposing objects are checked to see if they have separated into two or more parts, and rigid body motion is determined.

5. Conclusion

We have presented a method that for the first time integrates a fluid-based flame simulator, combustion model, heat transfer model, solid pyrolysis model, solid decomposition model, and rigid body simulator into a common framework. It is flexible, allowing for easy replacement of simulators in any one part of the model, fairly independently of the other portions of the model.

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