A Practical Simulation of Dispersed Bubble Flow

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Presented by Doyub Kim

ACM SIGGRAPH 2010
• Tons of Micro-Bubbles
• Mixture of Bubbles & Liquid
• Complex Bubble Interaction
Dispersed Bubble Flow
<table>
<thead>
<tr>
<th># Bubbles</th>
<th>1,570,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>7 sec/frame</td>
</tr>
</tbody>
</table>
\[\sum\]

\[
\begin{array}{ccc}
0.5 & 0.1 & 0.1 \\
0.2 & -0.2 & -0.3 \\
-0.8 & -0.6 & -1.2 \\
\end{array}
\]
Continuum Solver

\[ f_{\text{cell}} = f_{\phi_{\text{cell}}} - \sum_{i \in \text{cell}} \frac{4\pi}{3} \left( \frac{r_i}{h} \right)^3 \]
Continuum Solver

\[ \rho (u_t + u \cdot \nabla u) + \nabla p = \nabla \cdot (\mu \nabla u) + f \]

Advection

USCIP advection solver [Kim et al. 2008]
Continuum Solver

\[ \rho (u_t + u \cdot \nabla u) + \nabla p = \nabla \cdot (\mu \nabla u) + f \]

**Pressure**

\[ \sum_{\text{faces}} \frac{p_a^* - p_b^*}{\rho_{\text{faces}}} = \sum_{\text{faces}} u_{\text{faces}} \cdot n_{\text{faces}} \]

\[ \rho_{\text{face}} = \rho_{\text{gas}} + (\rho_{\text{liquid}} - \rho_{\text{gas}}) f_{\text{face}} \]
Continuum Solver

\[ \rho (u_t + u \cdot \nabla u) + \nabla p = \nabla \cdot (\mu \nabla u) + f \]

Diffusion

\[ \mu_{\text{face}} = \mu_{\text{gas}} + (\mu_{\text{liquid}} - \mu_{\text{gas}}) f_{\text{face}} \]
Global Motion of Bubbles

\[
\begin{bmatrix}
0.5 & 0.1 & 0.1 \\
0.2 & -0.2 & -0.3 \\
-0.8 & -0.6 & -1.2 \\
\end{bmatrix}
\]
Subgrid Stochastic Solver
Subgrid Stochastic Solver
Subgrid Stochastic Solver

Scattering Event \( \xi < s \)

\( s(x) = \nu \rho_{\text{gas}} [1 - f(x)] |u(x)|^2 \)

User Param Kinetic Energy
Parameter Comparison

\[ \nu = 0.25 \]

\[ \nu = 0.005 \]
Subgrid Stochastic Solver

Scattering Direction

\[ \cos \theta = \frac{2\xi + k - 1}{2k\xi - k + 1} \]

Diagram showing scattering directions for different values of \( k = 0.3, 0.5, 0.8 \).
Parameter Comparison

\[ \nu = 0.25 \]
\[ k = 0.9 \]

\[ \nu = 0.25 \]
\[ k = 0.1 \]
Parameter Comparison

\[
\begin{array}{llll}
\text{\(v = 0\)} & \text{\(v = 0.25\)} & \text{\(v = 0.25\)} & \text{\(v = 0.005\)} \\
\text{\(k = 0\)} & \text{\(k = 0.9\)} & \text{\(k = 0.1\)} & \text{\(k = 0.9\)} \\
\end{array}
\]
Bubble Path Instability
\[ \sum \]

Matrix:

<table>
<thead>
<tr>
<th>0.5</th>
<th>0.1</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>-0.2</td>
<td>-0.3</td>
</tr>
<tr>
<td>-0.8</td>
<td>-0.6</td>
<td>-1.2</td>
</tr>
</tbody>
</table>

\[ \xi \]
Demo
Rising Bubbles from a Bubble Agent

<table>
<thead>
<tr>
<th>Resolution</th>
<th>80x80x80</th>
</tr>
</thead>
<tbody>
<tr>
<td># Bubbles</td>
<td>2,600,000</td>
</tr>
<tr>
<td>Time</td>
<td>16 sec/frame</td>
</tr>
</tbody>
</table>
Real-world Comparison

Comparison with Real Footage
Melting Bunny

- Resolution: 160x192x96
- # Bubbles: 1,570,000
- Time: 7 sec/frame
Boiling Water

<table>
<thead>
<tr>
<th>Resolution</th>
<th>192x256x128</th>
</tr>
</thead>
<tbody>
<tr>
<td># Bubbles</td>
<td>1,160,000</td>
</tr>
<tr>
<td>Time</td>
<td>15 sec/frame</td>
</tr>
</tbody>
</table>
Implementation

System:
- Intel Core i7 920 2.66GHz, 6GB RAM

Numerical solver:
- Uniform staggered grid
- Multigrid for Poisson solver

Parallelization:
- OpenMP with 8 threads (hyper threading enabled)
Limitations

Approximated bubble dynamics:

• No per-bubble collision
• No merging
• No shape variation
Future Work
Conclusions

Efficient Method for Dispersed Bubble Flow
Thanks to...

- SIGGRAPH Reviewers
- Graphics & Media Lab. Seoul National University
- Eunchan Jo, Ji-Young Park, and Oh-Hwan Kwon at Sejong University
Thank You
Questions?