Sketching for Insight:
Trajectory Retrieval in VR with Flotation Data

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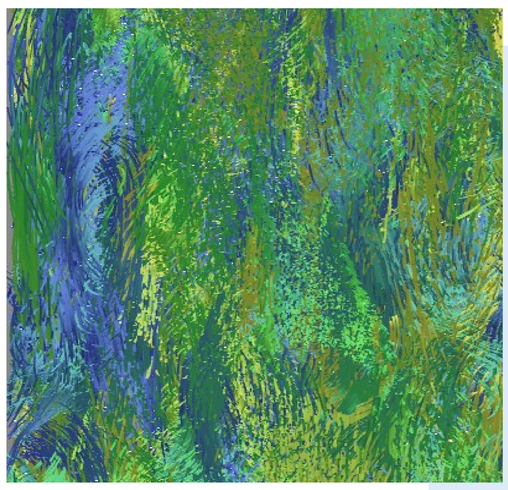
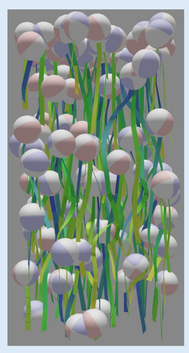
What Can We Learn from Sketching Through Data in Virtual Reality?

Dense 3D motion data is difficult to analyze with 2D tools—clutter and occlusion often hide important patterns, while automated methods like clustering offer limited flexibility for exploration. Shape-based similarity matching addresses this by highlighting trajectories with similar geometry, reducing clutter and guiding attention to relevant motion [1]. Building on prior work showing that VR sketching effectively captures conceived shapes in design tasks [2], we use it here as an intuitive way to define trajectory queries. We explored this approach in analysis sessions with a domain expert in flotation.



Challenging Data



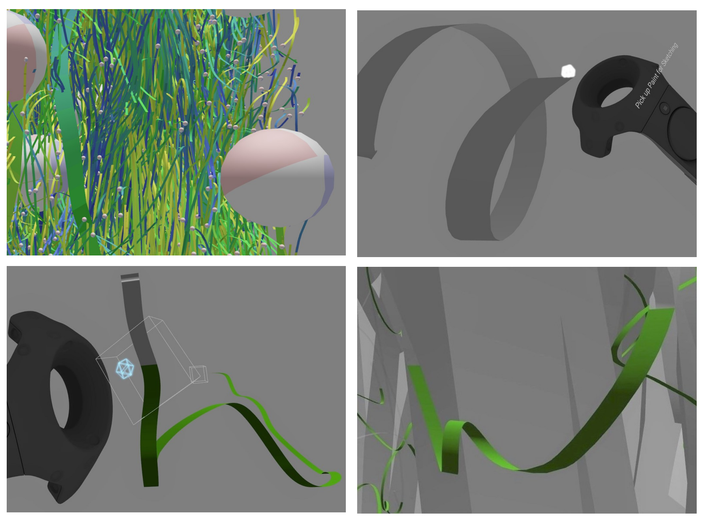
- Numerical flotation simulation [3] with 560 time steps over 0.5 seconds
- 4 million particle and 135 bubble trajectories

Color encodes time from yellow to blue

Our Immersive Analysis Tool

Visualizing
trajectories as colored ribbons and particles as textured spheres to illustrate orientation.

Selecting
a segment from sketched or existing trajectories to create a query.



Sketching
motion patterns directly in 3D space using VR controllers.

Retrieving
trajectories with symbolic encoding and edit-distance-based matching [1].

Typical Analysis Tasks

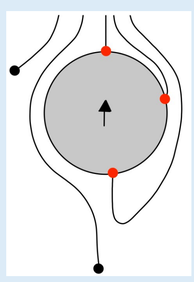
- **T1:** Characterize typical bubble motion
- **T2:** Identify common particle motion patterns
- **T3:** Locate regions of similar particle motion
- **T4:** Analyze particle–bubble interactions

A Real Exploration Scenario from Our Use Case

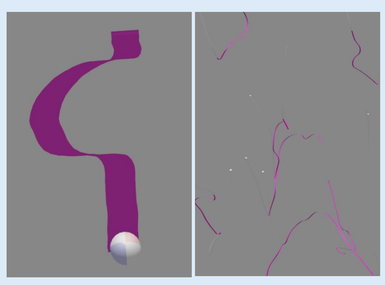
The expert began with a planar C-shaped sketch, based on a 2D drawing of their expectation that particles would move around rising bubbles (T4). The initial retrieval confirmed a few matching patterns.

To explore more complex motion, the developer—more experienced with 3D input—refined the planar sketch into a spiral-like path around the bubble utilizing the full 3D space. This revealed additional instances and even regions with multiple occurrences (T3). Time-encoded visualization showed that these motions were indeed caused by rising bubbles but were obscured in the dense dataset.

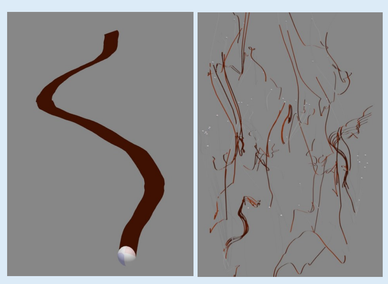
This shows how 3D sketching uncovers spatial patterns missed with planar input.



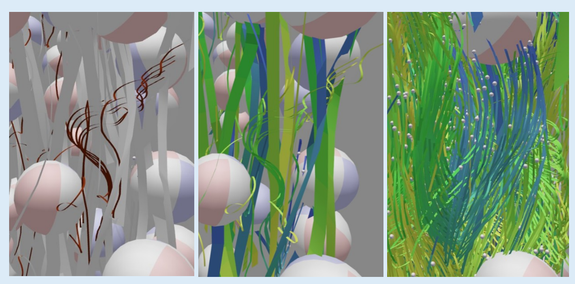
Expectations illustrated in 2D



Planar sketch and retrieval result for C-shaped path around bubble

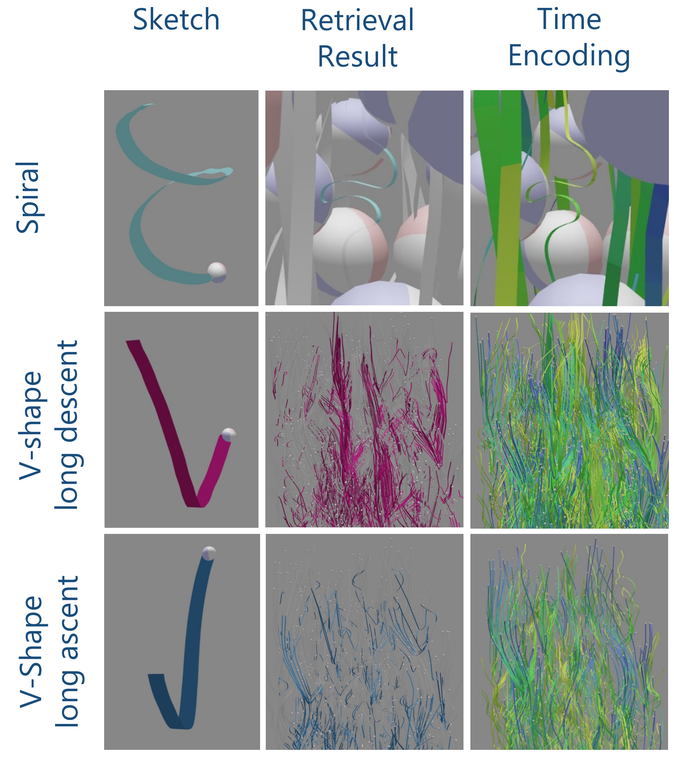


3D Sketch and retrieval result for spiral-shaped path around bubble



Detailed views of retrieval result with bubble trajectories (left), time encoding (middle) and unfiltered dataset (right).

More Retrieval Results



What We Already Learned

- Sketching revealed interpretable motion types: C-shapes around bubbles, spirals indicating turbulence and V-shapes for wake entry
- Results aligned with domain expectations, supported hypothesis exploration and revealed new insights
- The expert mainly used planar sketches, likely reflecting familiarity with 2D motion illustrations, and refined queries with segments from retrieved trajectories

What Still Needs Work

- Improve the precision of mid-air sketching
- Add adaptability to the retrieval algorithm (e.g. direction of motion)
- Improve result interpretation by visualizing similarity scores

Takeaway

Immersive sketching supports visual hypothesis exploration — simple planar sketches often serve as a starting point to retrieve complex 3D motion patterns, which can then be refined by sketching 3D paths or selecting trajectory segments from the results.

Your feedback is welcome and valued.
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[1] F. Kahlert and S. Gumhold. Partial Matching of Trajectories with Particle Orientation for Exploratory Trajectory Visualization. 2020. https://doi.org/10.2312/vmv.20201193
[2] S. Monty et al. Analysis of Immersive Mid-Air Sketching Behavior, Sketch Quality, and User Experience in Design Ideation Tasks. 2024. https://doi.org/10.1109/ISMAR62088.2024.00041
[3] B. Tiedemann and J. Fröhlich. Collision dynamics of particles and bubbles in gravity-driven flotation: A DNS investigation. 2023. https://doi.org/10.1002/pamm.202300290

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