

2D Polygonal Mesh Draining via Parametric AI Search

by

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University of California, Berkeley

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Peter Cottle

Abstract

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This is the part that explains the paper.

To Ossie Bernosky

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Acknowledgments

To everyone who helped me along this journey.

Chapter 1

Background

TODO

Chapter 2

Introduction & Motivation

A paragraph about manufacturing work pieces and jet cleaning

A paragraph about draining the fluid after cleaning. Oven approach vs rotating / draining approach.

Existing research [1] has been conducted to determine the “drainability” of workpieces. “Drainability” in this sense refers to the ability for a part to be fully drained by an infinite number of rotations about a particular axis. Water particles move between concave vertices while the workpiece is being rotated; they eventually either leave the workpiece or enter a cycle in the draining graph.

Existing software can sample all rotation axes over the Gaussian Sphere and produce a map of which rotation axes contain loops in the draining graph. These rotation axes that contain loops cannot be drained by an infinite number of rotations, so manufacturers know to produce fixtures that rotate the workpiece along a different axis.

Once an axis is chosen however, manufacturers have no way of knowing the duration of rotation needed. They also do not know the optimal speed of rotation (the speed that guarantees draining in the shortest amount of time). Because of this, there still exists a gap between the theoretical results of drainability and the implementation in industry.

Furthermore, the existing research only calculates drainability for rotation in one direction. It is fairly easy to imagine parts that are undrainable with rotations in solely one direction, but easily drainable with rotations in two directions. Omitting the possibility of bi-directional draining unnecessarily reduces the set of workpieces that are considered “drainable.”

This paper aims to bridge the gap between drainability analysis and industry implementation. Similar drainability analysis results will be produced, but a final control sequence of the rotation angle of the workpiece will be produced. Furthermore, bi-directional draining solutions will be produced, further expanding the set of workpieces that can be drained. These two objectives give rise to a fairly different approach than existing research.

Chapter 3

Physical Simulation of Water Particles

3.1 Basic Formulation

Here we talk about how water particles must be simulated as part of the drainability analysis calculation.

Many methods – smoothed hydrodynamic particles, etc etc

Another approach is to simply construct the kinematic equations and integrate in time. Euler's method, etc

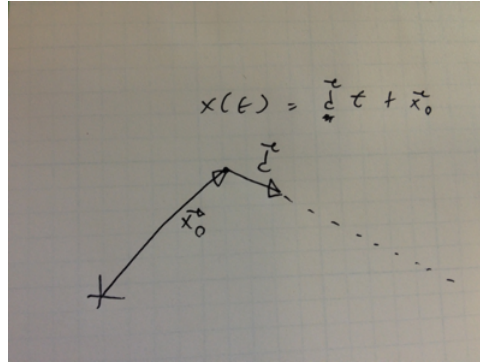
We will examine a parametric approach.

Parametric Equations (rays)

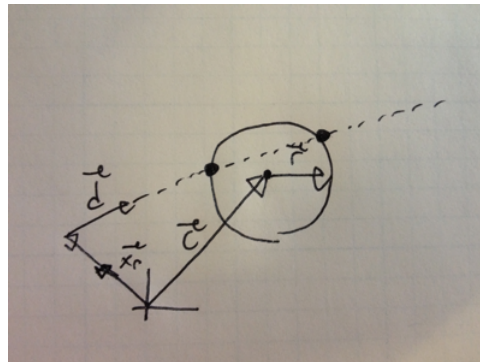
Parametric rays look like this (equation).

Geometric Primitive Intersections

Once parametric rays are defined, you can easily intersect them with geometric primitives



Example of sphere ray intersection equation.

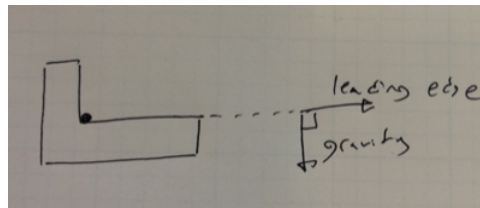


3.2 Previous Work

Previous work (Yusuke's work) involved a few simplifying assumptions about water particle simulation.

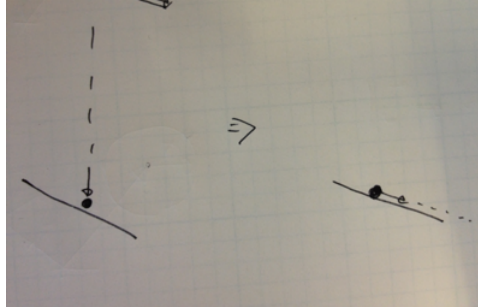
Infinitesimally Slow Rotations

The first was that rotations would be infinitesimally slow, meaning that gravity direction was always essentially perpendicular to the leading edge of the rotation when a particle fell.



Inelastic Collisions

The second was that particle collisions would be inelastic, meaning that velocities were instantaneously projected onto the plane or edge that they collided with.



Kinetic Energy Limitation

The last was that particles never accumulated kinetic energy above an epsilon value, meaning that they did not leave leading edges with a finite velocity. This means that all paths traced out by the particles were straight lines. This allowed for fast particle simulation but unrealistic particle behavior.

3.3 Adaption to Finite Velocities

This paper adapts the particle simulation to finite velocities and rotation speeds while maintaining the performant nature of the simulation.

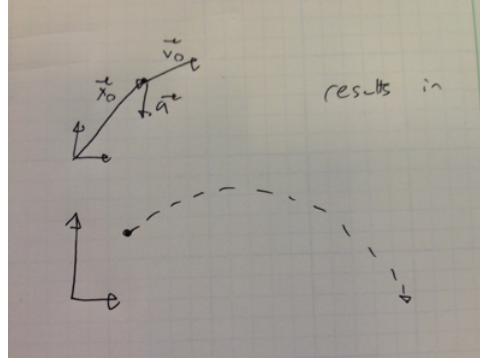
Parametric Equation Modification

Now our parametric equation includes an acceleration term:

$$\vec{x}(t) = \vec{x}_0 + \vec{v}_0 \cdot t + \frac{1}{2} \vec{a} \cdot t^2$$

Free Fall Equation

In free-fall, this leaves us with a parabolic equation of the particle's path. Kinematically valid, but assumes no aerodynamic drag.

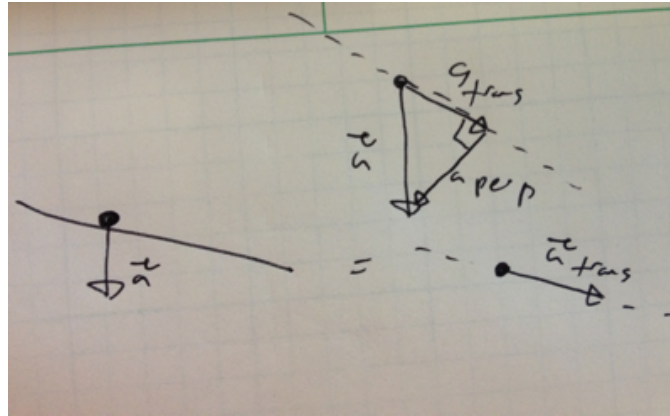


Sliding Equation

When the particle comes to rest against an edge in the workpiece, it begins to slide along this edge. The acceleration vector is projected along the edge, and the resulting component of acceleration is responsible for accelerating the particle.

Note that while the particle is now traveling along an edge, it is essentially the same as the freefall equation with a new projected acceleration.

$$\vec{x}(t) = \vec{x}_0 + \vec{v}_0 \cdot t + \frac{1}{2} \vec{a}_{\text{projected}} \cdot t^2$$



Rotation

We would like to simulate the particle during workpiece rotation. Since we no longer assume infinitely slow rotations, our particles will need to be simulated during workpiece rotation.

In this paper, we choose our frame of reference to be the $X Y$ axes that define the workpiece geometry. This means that when the workpiece rotates, our frame of reference stays fixed to the workpiece. During rotation, only the acceleration vector changes in direction – the rest of the math stays the same.

We see now how this rotating acceleration vector affects the two above equations.

Concurrent Rotation & Sliding Equation

When the particle is sliding on an edge, the acceleration vector is projected along the edge. A rotating acceleration vector, when changed, is equivalent to a fixed-direction vector with changing magnitude.

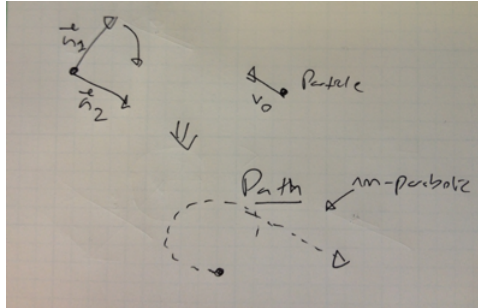
$$\vec{x}(t) = \vec{x}_0 + \vec{v}_0 \cdot t + \frac{1}{2} \vec{a}_{projected} \cdot t^2 \cdot mag_{accel}(t)$$

Assumption #1 - No concurrent Rotation + Freefall

When the particle is in free-fall, the acceleration vector is no longer projected along an edge.

$$\vec{x}(t) = \vec{x}_0 + \vec{v}_0 \cdot t + \frac{1}{2} \vec{a}(t) \cdot t^2$$

Although possible to integrate with numerical methods, no easy way of substituting into parametric equations and solving.



Elastic Collisions

Collisions are now elastic, meaning particles maintain a perpendicular velocity when colliding with an edge.

Planar Collision

When colliding simply on an edge, they bounce and transition back into freefall.

Planar To Sliding Transition

When the particles have some ϵ perpendicular velocity, they transition from freefall to sliding along an edge.

Sliding-Edge Collision

When sliding along an edge, the particle may encounter another edge. If this edge has a dot product greater than zero, it collides with the edge and enters freefall again.

Sliding-Corner Collision

If the next edge has a dot product less than or equal to 0, the particle is effectively “trapped” as long as the gravity vector points within the edge.

Conservation of Momentum

The only source of energy in this demo is the potential energy from gravity. Note that as the workpiece rotates, the gravity vector (and corresponding field) changes. This means that a particle in a low-energy configuration can transition to a high-energy configuration.

Settling Guarantee

The only addition of energy is from rotation, so in the absence of rotation, no energy is added to the system. Because the elasticity κ of the system is less than 1, energy dissipates as the particles are simulated throughout the workpiece.

Duration of Simulation

Because of this energy dissipation, the simulation is guaranteed to terminate in one of two ways.

Simulation End – Concave Vertex

Either the particle settles into a concave vertex with a kinetic energy less than ϵ , or

Simulation End – Workpiece Exit

The particle exits the workpiece, which is the goal of the simulation.

3.4 Results**Run Time**

It was fast, here are some numbers

Accuracy Comparison

It was accurate in finding intersections that some euler integration schemes would not.

With Euler Integration

3.5 Future Work & Discussion

Bounding Box Method Adaption

You could modify normal bounding box methods to use parametric equations instead.

Bounded Simulation Between Limits

There is a possibility that you could simulate between two arbitrary limits and “sweep” across the range of kinetic possibilities. Would eliminate the sampling we will see next chapter.

Chapter 4

Solution Search

4.1 General A.I. Search

General A.I. Search essentially expands from a start state and proceeds towards a goal.

State Space Formulation

The state space is the tuple of information that directly encodes the time-variant properties that describe your progress towards the goal. For pacman, the example is his position and the food.

Other parts of the problem that are not time-variant are considered part of the environment (for instance, the walls of pacman or the polygons in our workpiece here).

State Space Size

The size of the state space is all possible valid combinations of the components of the state space. E.G. for pacman, it's MN for an $M \times N$ sized board.

State Space Exploration

Exploration of a state space happens through a transition function that generates successors from a state from a list of available actions.

For pacman, this means that North/South/East/West produce different states. Transition functions can fail to return a state from an action if that action is invalid.

4.2 Adaption of A.I. Search

Our A.I. Search algorithms will be quite similar, but our state space approach is quite different.

Traditional Formulation

The traditional formulation for kinematic problems is to define the state of a particle as it's position, velocity, and acceleration. Successor function integrates in time.

Our State Space Formulation

Our state space formulation is instead either:

1. The concave vertex the particle is resting in
2. The particle is out of the workpiece

Our state space is thus dramatically reduced in complexity compared to the traditional formulation, meaning our state space size will be reduced dramatically as well.

Exploration

Instead, the bulk of the algorithm's work will be in the transition function, allowing us to determine what concave vertices we can reach from a given state.

4.3 Transition Function

Definition

Transition function returns states.

Sampling

We will sample from our available gravity directions and simulate a kinetic path from there.

Representative Coverage Between Limits

Try to get an even coverage over the space, sample with $\sqrt[3]{x}$

Graph Search

Reduce possibilities, prioritize by our "cost" for the algorithm.

Cost Sensitive Closed List

Essentially similar to CSCL because it is order-independent.

4.4 Search

Now we can search from a start state outwards

Uniform Cost Search

Using uniform cost, we always maintain optimality based on our cost.

Cost Function

Our cost function can be a variety of things based on the backwards path.

Time

Most popular is time, because time is money.

Energy - Rotation Angle

Second most popular is energy based on the rotation angle. This would be appropriate if the workpiece was well balanced but fixture generated a lot of friction while rotating.

Energy - Workpiece Center of Gravity

Another option is based on center of gravity if the energy from the workpiece rotations outweighed the friction in the motors.

Solution

Defined as the sequence of gravity transitions from each concave vertex to produce a particle path that exits the workpiece.

4.5 Control Sequence Generator

Now that we have a solution, we need to generate a control sequence for the workpiece rotator.

Sample-defined Rotations

These rotations are defined for us by the transition function.

Intermediary Rotations

Between these samples we don't have anything. What we do is just interpolate between the last sample and the beginning of the next sample with a cubic bezier curve.

4.6 Results

Run Time

Runs fast.

Part Complexity

Transition function is constant in best case, linear in worst case based on the number of polygon edges.

Demonstration of Solution

Go to this web address!

4.7 Future Work & Discussion

Could be improvements

Heuristics for A* Search

A* search can be added with heuristics. Distance to workpiece bounding box might be a good one, but that's essentially a radially symmetric heuristic, not very informative.

Chapter 5

Conclusion

TODO

Bibliography

- [1] James Moorer. “Signal Processing Aspects of Computer Music—A Survey”. In: *Computer Music Journal* 1.1 (1977).