Visual Simulation of Lotus Leave Effect

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Abstract

Lotus leave effect connected to the high water repellence and self-cleaning properties of lotus or similar kind of plants such as Rice, Cane, Tropaeolum, Opunita, Aquilegia etc. This work tried to model the water bubble which behaves differently on nano-surfaces and study the behavior of water on nano-surfaces without real fabrication. These visual simulations would guide to produce suitable surface for different materials using laser micro/nano fabrication methods. This paper focuses on the fundamentals related to water-repellence and creates a visual simulation using Maya Embedded Language (MEL) and Autodesk Maya application software. This research also explored the possibility of implementing biologically inspired materials and their physical and biological attributes. Further explore related laser equipment/methods and capabilities which how to create surface that close to water repellence surfaces.

1. Introduction

Thousands years before, human observe lotus leave effect and as evidences shows early Buddhist script uses to describe purity phenomenon using this effect. Lotus is a native plant to Asia and it symbolizes purity of any matter in Asian culture. The cleaning and water repellence abilities of the lotus leaf were not studied until 19th century. The phenomenon was first studied and recorded by Dettre and Johnson in 1964[1]. With availability and advancement of the scanning electron microscope (SEM) in the early 1970s, it helps researchers to find nano scale structures on the lotus leaf; which were not observe on most of other plants. This was far beyond its microscopic scale of the lotus leaf topography and it open new doors to nano properties. This lotus leaf effect grabs the attention and open the possibilities of its usage in our modern day living environment [2, 7].

Non-wetting and self-cleaning are the two properties from this magical lotus leaf effect. When a droplet of water lands on a lotus leaf it beads up, rolls off the leaf surface without leaving a trace of water behind and washes away any dirt along its path. This self-cleaning and non-wetting property fascinated scientist for long time and until recently, they realized that the non-wetting property is due to the Nano structure of lotus leaf which they term it Superhydrophobicity.

The purpose of this research is to study the fundamentals of self-cleaning effect and superhydrophobicity on different type of surfaces and the various types of liquid properties. There are few fundamental theories which support and demonstrate the lotus leaf effect. These theories cover properties of water and its cohesive, adhesive and viscosity properties. This paper will include the study of Nano scale surface features of lotus leaf (which gives its water repellence property). The research objective was to work on the modeling and simulation regarding lotus leaf phenomenon. The modeling part of the simulations uses mathematical expressions and different contact angle measurement. Autodesk Maya application software and Maya Embedded Language (MEL) scripts were used to create visual simulation of lotus leaf effect [2, 3]. For simulation, it shows water droplet falls from a slanted angle surface on and continue to a stable position. This study also explored the possibility of implementing materials not only based on visual properties but also based on physical attributes of biologically inspired surfaces.

Figure 1: A droplet takes up the dust covering a lotus leaf. (From [5]).

2. Background

2.1 Lotus Effect- Natural Model

Few decades ago, scientists and researchers thoroughly work on this
phemonenon of high water repellence and self-cleaning effect of the lotus leave and other similar existsents. Technically lotus effect can be describe as a surface property, which shows superhydrophobic and contact angle which is more than 150° with slight tilted angle of slope (more than 3 degrees). Therefore water rolls off surface and cleans the surface on its way [2].

Lotus leaf is covered with wax crystals on its surface as shown in left image of Figure 2. At higher magnification, it shows that another nano crystal layer can be seen, this enhances its water repellent ability considerably. Surface roughness was directly proportional to the repellence of the water droplet. This roughness can be described according to the models of Wenzel and Cassie.

![Lotus leaf SEM image](image1)

Figure 2: SEM-image of lotus leaf (Left image). The micro structural epidermal cells are covered with Nanoscopic wax crystals. Bar: 20 μm. (From [6]). A water droplet on a lotus leaf (right image).

“Non-Wêttbare” surface crystal wax helps to keep the water droplet on its surface and made the largest possible contact angle between the surface and the droplet. It forms a spherical droplet as shown in the right image of Figure 2 [6]. The lotus leave effect is created with the combination of surface forces and surface roughness properties. Contaminants larger in size (see the left image of Figure 3) than the cellular structure of the surface; it can be rested of the tip of the structure. When water contact with contamination it will absorb if, the absorption energy is larger than the removal energy [6]. Due to small contact area it can be removed by water easily (see the right image of Figure 3).

![Lotus leaf contaminating particle image](image2)

Figure 3: Left: Contaminating particle on a regularly sculptured wing surface of Cicada omi ( Bar:1 μm (From: [6]). Right: The Lotus-effect- contaminating particles adhere to the droplet and are removed when the droplet rolls off the surface. Bar: 50 μm. (From: [6]).

### 2.2 Patel Effect

Lotus leaf effect and Patel Effect are closely related; both having superhydrophobic properties due to secondary roughness properties. Whether its lotus leaf effect or patel effect will depend if the water droplet may roll off or stays on the surface; the surface which has ability to hold the droplet is called patel effect. The effect of the secondary and nano-scale roughness are not explicitly portrayed in the Wenzel and Cassie-Baxter equations, it has been proven to greatly enhance the superhydrophobicity of a particular surface [6, 7, 8, 9].

The best example from the nature can be found from rose petal. It shows great superhydrophobicity and yet it does not roll off the water beads even when the petal is hold upside down. This phenomenon exists because of the secondary roughness. This secondary or Nano-scale roughness can be achieved by either growing Nano-wires on the Micro-arrays to mimic the lotus leaf or scattering nanoparticles on the micro-arrays to introduce another layer of roughness at the surface and water droplet interface. Additional level of roughness can also be achieved by adding another layer of nano particles.

There are various physics principles used to describe the lotus effect [6, 7]. Recently, Zhang et al. [10] has introduced a deformable surface model for real-time water drop animation. Even though Zhang et al.’s deformable surface model simulates physically plausible water drop phenomena, less effort has been spent on external interaction with dust particles. Self-cleaning is another important feature associated with lotus effect and no previous visual simulations in CG has been focused on self-cleaning that would aid in making a realistic simulation of lotus leave effect. This paper would focus on dynamics of droplets and the way of drops move across superhydrophobic surfaces as well as interactions with dust particles.

### 3. Simulations

This section begins heavy production experience with simulating of water droplets and hydrophobic surfaces in Maya [3]. The basic approach begins with the introduction to how models are planned and modeled in MEL scripts [4], and which would be the main point of interest in this section.

### 3.1 Appearance of hydrophobic Surface

This section explores the modeling of appearance of the hydrophobic surface, that covering used methods in more detail and exploring how to use 3D and 2D textures for visualizing surfaces. In order to create the appearance of the hydrophobic surface, procedural fractal textures were used. There are two fractal textures were connected by using shading network in Hypershade window.

The Hypershade window allows the connection of various Maya nodes. Technically speaking, a node is a construct that holds specific information plus any actions associated with that information. As shown in Figure 4, fractal textures connected to blinn material. In order to add details, Perlin noise function has been used [11]. Maya’s Fractal texture is a more complex variation of classic 2D Perlin noise in which turbulence (the averaging of multiple scales) is added for detail.
In the hypershade network as shown in Figure 4, the Specular Color of the blinn material (CothColor) node is connected to the outColor of second fractal texture (fractal2). The outColor of first fractal texture (fractal1) is connected to the colorGain of grid texture (grid1) and its uvCoord. The outAlpha of grid texture is connected to the bumpValue of bump2D utility (Figure 4), thus making the realistic surface details. In order to visualize bump values in the scene, outNormal of bump2D utility is connected to normalCamera of blinn material (CothColor). Figure 5 shows the rendered view of surface with water drops.

![Figure 4: The hypershade network for appearance of the hydrophobic surface.](image)

3.2 Lighting of Water Drops

Individual water droplets, a minute form of calm water, reveal a strong tendency to refract. As shown in Figure 5, the texture pattern of the surface is magnified by each droplet. The degree of refraction is defined by a refractive index. Although air has a refractive index slightly above 1.0, water has a refractive index of 1.33. When the water’s surface is curved by surface tension, the perceived refraction is stronger than the equivalent refraction provided by a flat surface. The surface curvature acts as a convex lens, causing light rays reflected off the surface to diverge as they are refracted through the water toward the viewer. In addition, the refraction process creates “hot spots” within the drops. These spots are found in caustic regions. Caustic regions are areas in which light rays are focused by materials such as water. In other words, light rays entering the water drop converge toward a focal point. Although the mental ray Caustics attribute is able to produce caustics. Nevertheless, we can simulate caustics by mapping the material’s Incandescence attribute.

![Figure 5: Rendered view of water drops on the surface.](image)

3.2.1 Simulation of Hydrophobic Surface

This section will focus on simulate and understand how the various collision of the water droplet, such as collision between, soft body, rigid body and particles, can be used together to visualizing and simulating hydrophobic surface. In the simulation, water droplet is acting as a soft body, surface acting as a rigid body and dust acting as particles. Any polygon mesh modeled in Maya can be converted into a dynamic object (also known as an nDynamic object); there’s nothing special about the way the polygon object needs to be prepared. The only restriction is that only polygon objects can be used. NURBS [12] and subdivision surfaces can’t be converted to dynamic object. Therefore, first NURBS objects should converted into polygons.

![Figure 6: The MEL script driven simple user interface for modeling hydrophobic surfaces](image)

The procedural modeling of hydrophobic surface has implemented with MEL scripts (see Figure 6). The MEL script[3, 4] driven simple user interface provides several parameters such as surface dimensions, patterns, and level of vertex extrusion, which can guide to model different hydrophobic surfaces as shown in Figure 7.

![Figure 7: Different hydrophobic surface patterns created by MEL-driven interface.](image)
### 3.2.1 Water Droplet as a Soft Body

Typically *nCloth* in Maya is used to make polygon geometry behave like clothing, but *nMesh* can actually be used to simulate the behavior of a wide variety of deformable materials. Everything from concrete to water volumes can be achieved by adjusting the attributes of the *nCloth* object. *nDynamics* uses the Nucleus dynamic system as *nParticles* and applies it to the vertices of a piece of geometry. An *nCloth* object is simply a polygon object that has had its vertices converted to *nParticles* (see Figure 7). A system of virtual springs connects the *nParticles* and helps maintain the shape of soft-body like a water volume. *nCloth* objects has used to make external collisions and self-collisions. Because *nCloth* objects automatically collide with other nDynamic systems (such as *nParticles* and *nRigids*) that are connected to the same Nucleus solver, and an *nCloth* object collides with itself.

![Figure 7: A polygon object for water droplet that has had its vertices converted to nParticles.](image)

An important phenomenon related to hydrophobicity is bouncing droplets. It can be bounced off as a soft-body, when a droplet impacts superhydrophobic surface with a certain velocity. There are essentially two types of *nCloth* objects: active and passive. Active *nCloth* objects are the ones that behave like cloth or soft-body. They are the soft, squishy, or bouncy objects. Passive objects are solid pieces of geometry that react with active objects. For our visualizations, to simulate a hydrophobic surface, the water droplet would be the active *nCloth* object, and the surface would be the *nMesh* passive collider object. The surface prevents the water droplets from falling in space. Then a bouncing elastic droplet hits a hydrophobic surface as shown in Figure 8.

![Figure 8: A bouncing elastic droplet hits hydrophobic surface](image)

The modeling of the dynamic droplet considered external forces and self-collision. The influence of external forces simulated with gravity, surface collision, friction, viscosity, and air density. The parameter values of the external forces have saved as presets under the different simulation conditions of external forces. When user is going to simulate, these presets can be loaded by clicking Presets button, it will show all pre-simulated and saved data. This will save a lot of time and work. The self-collision enables the droplet mesh collides with its own output mesh by using Maya Nucleus solver [3, 4]. Maya collision flags used to enable the type of self-collision such as vertices collide, edges collide and faces collide. The following Figure 9 shows two different types of self-collisions of droplets, edge collision (right image) and vertex collision (left image).

![Figure 9: Different types of self-collisions in a droplet, edge collision (right image) and vertex collision (left image).](image)

The simulations considered volume pressure method to conserve internal volume of the water droplets, combined with a low stretch resistance and no damping. When increasing the stretch resistance, triangle density can be better preserved, however the substance will not be as free to flow.

In order to increase the complexity of self-collision, it needs to increase the number of self-collisions iterations. In general full surface self-collisions should be used, and the self-collision width can be used to control the minimum thickness of flows. A passive collider object (superhydrophobic surface) can be animated, and the active water droplets would react to the animation. So, user can keyframe the surface tilting, and the water droplets would slide off the surface based on its dynamic settings.

![Figure 10: Droplets on the superhydrophobic surface with different contact angles, top: same contact angle, bottom: different contact angles.](image)
Figure 10 shows the simulation results for different contact angles, based on the Wenzel equation [13] relates the contact angle of a water drop upon a rough solid surface. Simulations assumed that there are no any air pockets in solid-liquid interface.

3.2.2 Interaction of Particles with Water-droplet

There is a qualitative understanding that water-repellent surfaces do also repel dust and other contaminants can easily be washed from them by flowing water. There is no quantitative theory has been explored on self-cleaning that would relate, for example, the size and contact angle of a droplet with size of a contaminating particle being washed away. To create interaction of dust particles with water droplet for simulating self-cleaning of a superhydrophobic surface, nParticles and nCloth objects were considered. Creating dynamic interaction between nParticles and nCloth objects is quite easy because both systems can share the same Nucleus solver [4]. The collision properties of nDynamics make effects that were extremely difficult to create in the Maya software, but it is very easy to create with MEL scripts. However, if we are using MEL to build many nodes, attributes, connections, and expressions, we would prefer to be able to automate installing such an expression. Use MEL commands with caution when you develop particle expressions, as they may be creating or destroying nodes, or they might force recalculation of part or the entire scene dependency graph once for each particle on each frame. This can be quite slow.

Ordinary expressions control per-object attributes. Particle expressions affect per-particle attributes and are executed differently from ordinary expressions. For every frame, a runtime particle expression is executed once for each particle, which means that operations that seem quick when used in an ordinary expression can slow the scene's evaluation to a self-cleaning in a particle expression for setting goals. Also, user can choose to execute a created particle expression (presets) once on the frame when each particle is created. The created droplets(nCloth objects) on the surface can be used to attract dust particles, dust particles (nParticles) can fill water droplet and cause them to clean the hydrophobic surface (see Figure 11 and 12).

4. Discussions

Designing of laser fabrication pattern is challenging area where different factors such as depth of pattern and size of Nano spikes, laser safety etc, have to be considered. Safety of the laser machining and machine is one of the most important parts since it is comparatively common for laser cutting industry. Therefore, it is very important to study and implement the pre-visualization tools for the industry of Nano-scale laser fabrication. For this purpose, the modeling of bio-inspired surfaces and how does it visualize, pre-visualization methods with Maya software and MEL scripts have successfully implemented. As graphic application software, it was challenging to simulate without implementing physically-based attributes for the dynamics of the droplets and superhydrophobic materials.
While implementing the simulations, this work concerned the proper usage of the surface parameters, designing customizable attributes for some special components like roughness, different grid patterns and considering physical parameters and coming up with a working simulation model (see Figure 13). For example, a proper control of roughness constitutes the main challenge in producing a reliable superhydrophobic surface, it is possible to visualize and demonstrate a rough surface from modeling of initial hydrophobic surface by using our MEL-driven modeling interfaces. Figure 14 shows the water droplets slide off the tilted hydrophobic surface. The material modeling in the Maya is considering appearance of the materials. Our work explored the possibility of implementing materials not only based on visual properties but also based physical attributes of biologically inspired surfaces.

![Figure 14: The water droplets slide off the tilted surface](image)

5. Conclusion

We have presented a visual simulation of lotus leave effect that allows us to study the dynamics of drops spreading and moving across superhydrophobic materials. By using our implementations, the interactions of a water droplet with superhydrophobic materials can be visualized. This allows a better understanding of the water droplets and thus possibly expanding the usage of superhydrophobic materials. Integration of the MEL-based modeling interface and of the simulation model is expected to be useful for more general systems.

In the future work, we plan to test various dynamic simulation models, such as biological inspired simulation and natural surfaces, which support a greater variety of bio-inspired designs. Future work also wish to explore further implementation of more independent system focusing on full GPU acceleration for high performance simulations. We are also interested in finding better ways to simulate quantitative self-cleaning effect based on measured data. How to improve the system connectivity with a laser cutter is another problem that we would like to investigate.

References