Eggceeding Eggspectations: Modeling Realistic Virtual Reality Cooking

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Abstract

Current VR cooking applications and games abstract the true experience of cooking into simple objects, leading to a user experience that doesn't truly mirror that of an actual cooking scenario. Real cooking involves complex visual, audio, and haptic feedback that isn't emulated in virtual environments; creating more precise and realistic interactions can help improve the VR cooking experience. In this paper, we explore techniques to simulate realistic cooking, specifically exploring the process of cooking an egg from start to finish.

1 Background & Related Works

1.1 VR Cooking Visuals

Creating a compelling visual in a VR cooking application requires several components working in tandem, such as accurate textures, realistic changes over time, and physics-based interactions with objects in the environment. Early works in this field focus on the effects of physical and chemical changes on the coloring of food, especially with regards to darkening, charring, and burning. Different shades of colors are specified for each material, and applied during the various cooking stages based on the real-time thermal conductivity and heat transfer [KH13]. Additionally, mesh models are created for different ingredients based on the distribution of heat and compounds across each item (for example, the fattier parts of steak will have a smaller thermal conductivity coefficient).

Expanding on this foundation, computer graphics research has thoroughly investigated multi-material fluid simulations and phase transitions. Packages such as Fluid Dynamic Shaders which implements a fluid simulation pipeline using compute shaders. These simulations leverage the GPU to model phenomena such as advection and diffusion by computing velocity, dye, temperature, etc. using gather operations. Yang et al. adopt a different approach, however, by integrating phase-field methods with multi-material simulation to allow for modelling of liquids and solids and the phase transitions between them [YCL+17]. We create our fluid simulation by leveraging the techniques and equations from aforementioned papers while using a less resource-intensive environment to illustrate fundamental fluid and solid interactions.

1.2 VR Cooking Haptics & Audio

To establish an immersive setting that enables users to feel fully present and engaged within their surroundings, the goal is to construct a multi-sensory environment that connects with the user via spatial audio and passive haptic feedback in addition to photorealistic visualizations. The research conducted by Guarese et al. in their paper titled "Cooking in the Dark: Investigating Spatial Audio as an Assistive Technology for the Visually Impaired" involves the creation of a game-like setting where users are required to navigate an unfamiliar environment using solely audio cues and tactile feedback [GBB+21]. The authors achieve this by enabling sound to be projected from different objects to aid users in finding the necessary resources and using real objects and props in the interactive game environment.

Additional research conducted by Korematsu et al. in "Acoustic Event Detection for Cooking State Recognition" aims to enhance cooking support systems by understanding differences in distributions of cooking sounds [KSM19]. To achieve this, they employ a dynamic recording approach which involves continuously recording audio throughout the entire cooking process, in diverse environments. To improve cooking state recognition, downsampling techniques are applied to the audio clips for effective feature extraction.

2 Methodology

In this section, we describe three major features that help create a realistic VR egg cooking simulation:

- adding fluid dynamics for a raw egg breaking into a pan and forming into a solid,
- adding material changes with the addition of heat while an egg is cooking, and
- adding audio and haptic feedback to create an immersive cooking process.

2.1 Fluid & Solid Dynamics

Our simulation of an egg in Unity focuses on three fundamental physical characteristics: appearance, cohesion, and reaction to heat. For appearance, we utilize the Unity Particle System in conjunction with the Unity Physics Engine to simulate the motion of the liquid. We create separate particle systems for the egg white and yolk, since the fluid properties of these two components vary greatly. As visible below, key differences between the two particle systems include velocity, size, and shape (what surface the particle system is released from).

To that end, we also develop customized materials to apply to each particle system, allowing for individual adjustments of color, specularity, opacity, and related parameters. Despite these efforts, we encountered limitations in achieving a desired visual blur effect that would enhance the "fuzziness" of the egg liquid particles.

Finally, we tackle modeling the influence of heat on the egg liquid, focusing on the processes of solidification and denaturation. To achieve this, we implement a form of particle attraction to keep the egg particles close together and invariant to external forces. We manipulate collision properties of the particle system such as the dampening, which determines the fraction of speed that particles lose post-collision, and the bounce, which controls the force applied to each particle after a collision.

2.2 Coloring & Material Changes

Mimicking the cooking experience of an egg requires key visual changes, such as fluid to solid transitions (above) and shifts in opacity and color. We model changes in color over time for the dual particle system by creating a series of equations for the egg white, egg yolk, and overall opacity (alpha) of the system.

The opacity of the egg white increases proportionately with how long the egg white has been cooking, and is scaled by a rate variable. The egg yolk undergoes similar changes, but instead of increasing only in opacity, changes from a light orange to a darker yellow proportionately with cook time. Figure 2 shows an egg throughout the cooking process as these changes are applied.

2.3 Audio & Haptics

There are many audio and haptic signals that users experience in a real cooking experience. We focused on 3 audio signals - egg cracking, egg breaking, and oil sizzling - and haptic feedback for egg cracking and breaking.

2.3.1 Egg Cracking and Breaking

To simulate egg cracking, we obtained a pre-recorded sound of an egg cracking and breaking [egg12]. This audio was split to separate the two actions. The egg cracking process is described below.

1. The user picks up an egg using a proximity grab within a small distance d. This has the effect of providing visual feedback that the user is holding an egg.
2. The user brings the picked up egg towards the pan to have the egg's collider collide with the pan. This is similar to how real users crack an egg on the pan.
3. The cracking sound is triggered and played once.

The egg breaking process is triggered with user actions.

1. The user collides the egg with the pan at least k times. This cracks the egg enough that it's ready to break.
2. The user brings the controllers close together (within a pre-defined distance d_1) to simulate positioning their fingers near the center of the egg.
3. The user pulls the controllers apart (outside of a pre-defined distance d_2) to simulate pulling apart the two halves of the egg.

These actions together trigger the particle system described in Section 2.1.

Figure 1: An Egg Throughout The Cooking Process

2.3.2 Oil Sizzling

The oil sizzling sound was sampled from a pre-recorded sound of potatoes deep frying in oil [oil21]. This sound sounded very close to the sound you might expect (the sizzle and pop) of hot oil hitting the liquid of a raw egg. The oil was triggered after the egg breaked into the pan. To model how the sound of oil changes with objects being added and oil being depleted from a pan during cooking, the following formulas were used to dynamically change the volume:

$$v_t = (1 - c_t) * (1 - o_t) * v_0 \tag{1}$$

where v_t is the volume at time t, c_t is how cooked the object is at time t, and o_t is how much oil is remaining at time t. The values of "cooked" and oil remaining are defined as follows:

$$c_t = r_c * t \tag{2}$$

$$o_t = r_o * t \tag{3}$$

where r_c is the rate at which an object cooks and r_o is the rate at which the oil is consumed by the object. This framework can be extended to any object cooking in oil (not just eggs).

2.3.3 Haptics

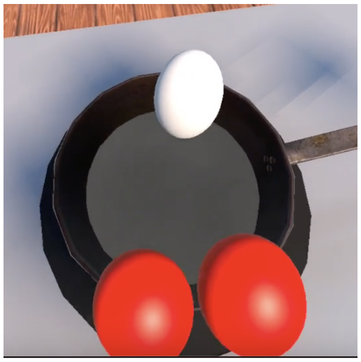
Although, we weren't able to implement haptics in our final submission, we could follow a similar strategy to oil sizzling from Section 2.3.2 to dynamically change the intensity of the haptic feedback. Instead of cooking rate and oil consumption rate impacting the intensity of haptics, we could use object velocities:

$$h_c = min(|v_e|, h_{max}) \tag{4}$$

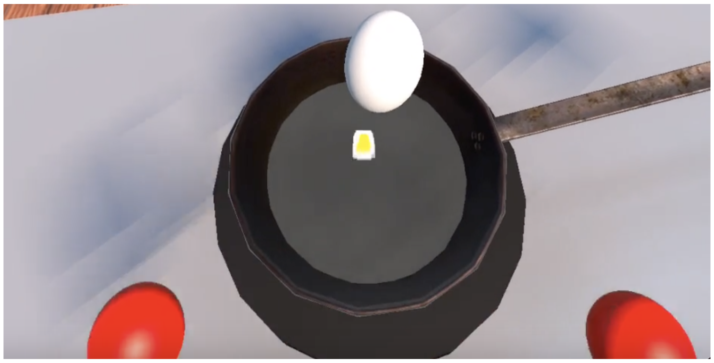
where h_c is the intensity of the cracking haptics and v_e is the velocity of the egg as it hit the pan. For egg breaking, we could use the velocities of the controllers being pulled apart:

$$h_b = min(|v_{rc} - v_{lc}|, h_{max}) \tag{5}$$

where h_b is the intensity of the breaking haptics, v_{rc} is the velocity of the right controller, and v_{lc} is the velocity of the left controller. This would provide haptic feedback that corresponds well with the visual signals that a user receives.



(a) Breaking an Egg - Step 1



(b) Breaking an Egg - Step 2

Figure 2: Breaking an Egg (Hands are shown as red spheres.)

3 Conclusion & Future Work

We have presented a precise and realistic VR cooking experience that combines simple objects with complex visual and auditory interactions to make the game more immersive. Our proposed methods accurately model multi-phase behavior, reflect the physical effects of heat transfer on multi-phase objects, and employs spatialized audio via prerecorded sounds to create an engaging activity. Our simulation is simplistic and resource-efficient, and thus able to run without demanding hardware requirements.

Further effort is needed to create custom shaders to enhance the visual blur effect on the particles. Additionally, the physics simulation can be augmented by modelling the liquid to gas transition with steam to simulate the heat and moisture released by the egg. By adding more photorealistic assets using the Unity Photogrammetry workflow, we can add more ingredients to demonstrate more complex physical interactions. Combining these assets with new binaural audio sources and sounds will allow us to illustrate a more holistic approach for the user's VR cooking experience.

References

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