Animating Parametric Kinetic Spinner in Virtual Reality

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(a) Parametric Kinetic Spinner (b) Animated Kinetic Spinner (c) Animated Parametric Kinetic Spinner in Virtual Reality

Figure 1: This figure shows the results of animating parametric kinetic spinner in virtual reality. Given user-specified parameter settings, our approach automatically generates a parametric kinetic spinner as shown in (a), then our approach animates this parametric kinetic spinner as shown in (b) and displays this animated parametric kinetic spinner in VR context as shown in (c).

ABSTRACT

In this paper, we present a novel approach to animating parametric kinetic spinner in virtual reality. Served for kinetic art edutainment purposes, parametric kinetic spinner is a visually captivating kinetic sculpture that can be dynamically adjusted based on different parameters. More specifically, parametric kinetic spinner is a particular type of kinetic wire sculpture designed with multiple parts, allowing for a wide range of configurations. With our approach, users can modify parameters such as kinetic spinner's size, shape, material, and rotational speed. Interacting with these parameters and animating parametric kinetic spinners in the VR context enables users to explore the kinetic spinner's behavior and aesthetics in real time within an immersive virtual environment. By integrating the parametric kinetic spinner into a virtual reality platform, we aim to create an engaging and immersive experience for users. We discuss the technical aspects of creating and animating the kinetic spinner in VR, explore the potential applications, and present the advantages and challenges of this innovative concept.

CCS CONCEPTS

• **Computer Graphics**; • **Interactive Systems**; • **Virtual Reality**;

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KEYWORDS

Parametric Modeling, Virtual Reality, Kinetic Spinner Design

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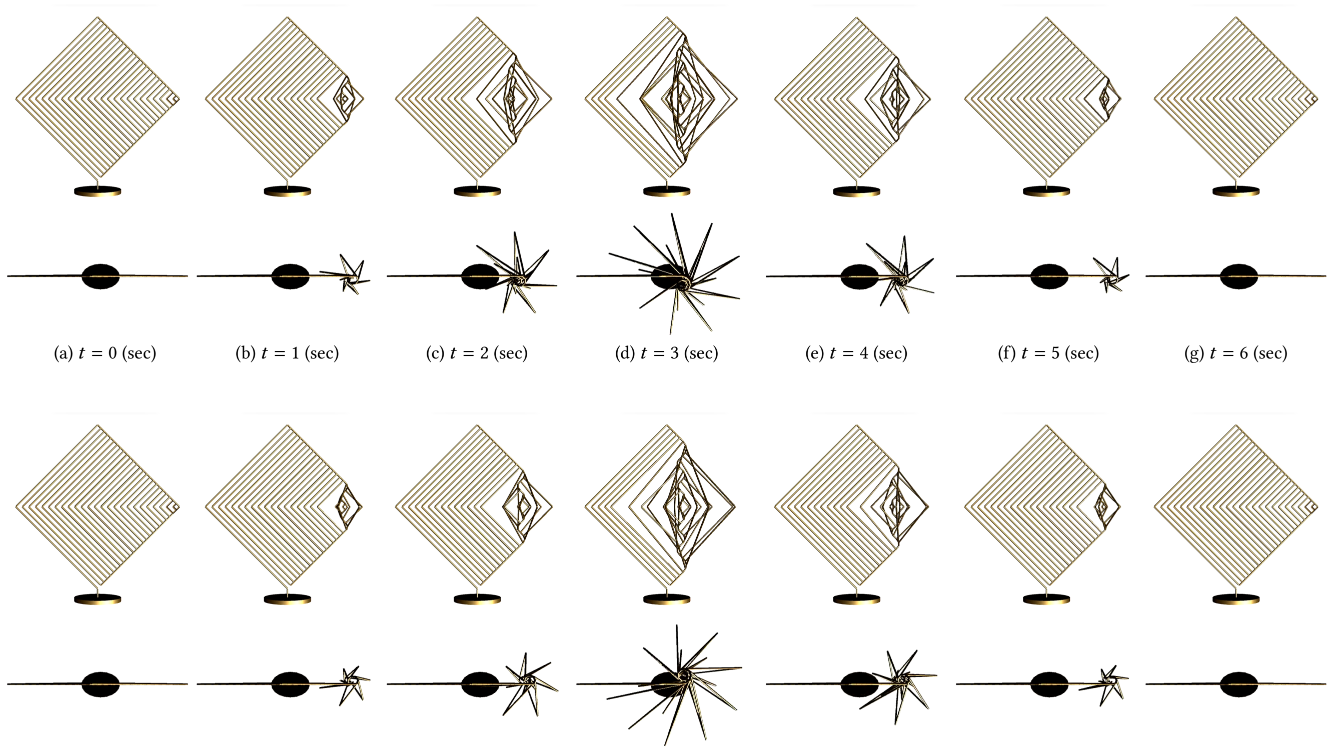
1 INTRODUCTION

kinetic spinner [20], a type of mesmerizing kinetic toy designed to spin rapidly around a central axis [15], is a stress relief kinetic wire sculpture inspired by math and the Fibonacci sequence [24]. Kinetic spinners are usually lightweight, making them easy to carry and manipulate with one hand. Kinetic spinners gained significant popularity as a fad toy, especially among children and teenagers. Originally intended as stress-relief toys to help individuals relax, meditate or concentrate, kinetic spinners quickly became a mainstream sensation embraced by people of all ages. The spinning motion of kinetic spinner is achieved by holding it using a hand and giving it a flick of wrist [17] or hanging it using a magnetic stand and giving it a push [16]. Once spinning, the toy can maintain its rotational motion for an extended period due to its low friction design and balanced weight distribution. Kinetic spinners come in various shapes, colors, and materials to enhance their visual appeal [18]. They are often marketed as stress remover or entertaining gadgets because of their mesmerizing waves of soft turning motions. Meanwhile, the captivating and intricate dynamic features of kinetic spinners extend them versatile tools that beyond mere entertainment and hold the potential to serve as educational instruments for kinetic art, performance art [19], and physics.



(a) $t = 0$ (sec) (b) $t = 1$ (sec) (c) $t = 2$ (sec) (d) $t = 3$ (sec) (e) $t = 4$ (sec) (f) $t = 5$ (sec) (g) $t = 6$ (sec)

(g) $t = 6$ (sec) (h) $t = 7$ (sec) (i) $t = 8$ (sec) (j) $t = 9$ (sec) (k) $t = 10$ (sec) (l) $t = 11$ (sec). (m) $t = 12$ (sec)

Figure 2: Animated Parametric Kinetic Spinner.

As Virtual Reality (VR) [27] has opened up a plethora of opportunities for interactive immersive experiences that transformed the way users step into virtual worlds [4], interact with digital content [3], and engage with virtual dynamic objects [1], the concept of parametric kinetic spinner adds an exciting dimension to VR simulations and animations. There have been recent research works exploring the integration of parametric designs interfaces to enhance VR applications. By using parametric design or procedural modeling methods, researchers are able to generate complex geometries and interactive elements in real-time, resulting in highly customizable and visually stunning VR animations [6, 11, 21, 26] and VR simulations [9, 10, 14, 25, 28]. These advancements hold the potential to revolutionize various fields, from architecture design [2, 8, 22] to gaming [13, 23] and edutainment [5, 7, 12], by offering synthesized virtual worlds that adapt to users' preferences.

However, as a novel research problem, there is an absence of existing research works that specifically concentrate on animating parametric kinetic spinners in virtual environments. Therefore, in this paper, we bring the parametric kinetic spinner to life in VR, aiming to enhance user engagement and immersion. To enable intuitive simulations with the kinetic spinner in virtual environments, we propose a novel parametric modeling approach and leverage the capabilities of VR hardware such as Oculus Quest 2 for preliminary user study. In our proposed approach, kinetic spinners are designed with parametric functions and procedurally generated as 3D models, their animations and rotational movements are driven by mathematical formulations based on physics rules and they are validated through a series of numerical and user experiment results.

2 OVERVIEW

Figure 2 shows the animation process of a simulated kinetic spinner. The Figure consists of multiple subfigures, each presenting a front view (above) and a top view (below) of the spinner at different time intervals, with a precision of one second. At the time $t = 0$ seconds, the spinner is at its initial position, with its rods aligned vertically and symmetrically spread out, forming a "square" shape in a concentric pattern at the front view, with its top view showing a shape of "straight line". As time goes by, until the time $t = 3$ sec, the rods are rotating clockwise to a maximum twist angle while the shape of the rods is twisted into a spiral curve in the top view. Until the time $t = 6$ sec, the rods are rotating counterclockwise to their initial position. Due to the rotational inertia, from the time $t = 6$ to $t = 12$ sec, the rods are rotating in the opposite direction, and in the end, it gets back to the initial position as shown in (m).

3 TECHNICAL APPROACH

In this paper, we propose a novel mathematical approach to automatically simulate the animation process of kinetic spinner. In our approach, the kinetic spinner's geometric shape is represented with parametric functions. Let $y = f(x), x \in [-1, 1]$ denotes the parametric function that describes the shape of rods, let l denote rods length, let n denotes rods count, then, the geometry of i^{th} rod's upper-left corner ${}^{\diamond}\mathbf{y}_i(x)$ is calculated with the following equation:

$$ {}^{\diamond}\mathbf{y}_i(x) = nl\left(x + \frac{i-1}{n}, f(x), 0\right), x \in [-1, -\frac{i-1}{n}], $$

geometry of i^{th} rod's upper-right corner $\mathbf{y}_i^{\diamond}(x)$ is calculated as:

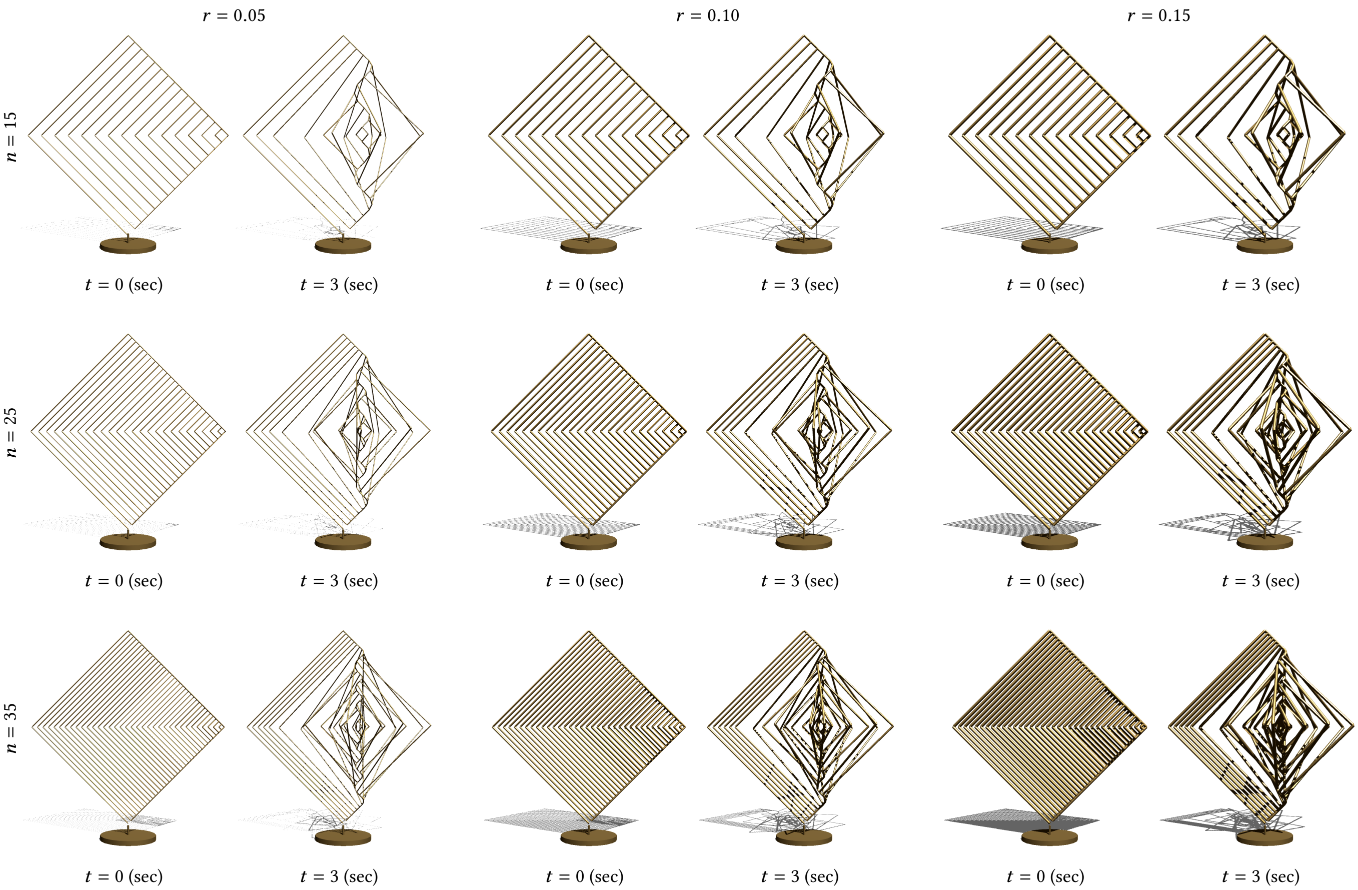


Figure 3: Changing Parameters. This figure shows the experiment results of changing parameters of rods' count n and radius r.

$$\mathbf{y}_i^{\diamond}(x) = nl\left(x - \frac{i-1}{n}, f(x), 0\right), x \in [\frac{i-1}{n}, \frac{i}{n}],$$

geometry of i^{th} rod's lower-left corner ${}_{\diamond}\mathbf{y}_i(x)$ is calculated as:

$$_{\diamond}\mathbf{y}_i(x) = nl\left(x + \frac{i-1}{n}, -f(x), 0\right), x \in [-1, -\frac{i-1}{n}],$$

geometry of i^{th} rod's lower-right corner $\mathbf{y}_{\diamond i}(x)$ is calculated as:

$$\mathbf{y}_{\diamond i}(x) = nl\left(x - \frac{i-1}{n}, -f(x), 0\right), x \in [\frac{i-1}{n}, \frac{i}{n}].$$

Rotation. Each rod's rotation follows a periodical pattern through a sine function. Let $\theta_{\max}$ denotes the maximum twist angle, then, the i^{th} rod's rotation angle $\theta_i(t)$ is calculated with following equation:

$$\theta_i(t) = \min\left(\theta_{\max}\left(1 - e^{-\kappa\frac{i}{n}}\right), nd|\sin(\omega t)|\theta_{\max} - \sum_{j=i+1}^{n}\theta_j(t)\right),$$

where resilience $\kappa = 3$, delay $d = 0.65$, and angular speed $\omega = 50$.

Position. As each rod is connected with its adjacent rod, therefore, the position of i^{th} rod at time t is $\mathbf{p}_i(t)$ that can be calculated as:

$$\mathbf{p}_i(t) = \mathbf{p}_{i-1}(t) + \frac{l}{n}\left(\cos\psi_i(t), 0, \sin\psi_i(t)\right),$$

where $\mathbf{p}_1(t) = \mathbf{0}$ and $\psi_i(t) = \text{sgn}(\sin(\omega t))(\theta_{i-1}(t) + \theta_i(t))$.

4 EXPERIMENT RESULT

In order to validate the efficacy of our proposed technical approach, a group of experiments is conducted on animating parametric kinetic spinner with different settings. We implemented our proposed approach using Unity 3D with the 2019 version and generated these experiment results with the hardware configurations containing Intel Core i5 CPU, 32GB DDR4 RAM, and NVIDIA GeForce GTX 1650 4GB GDDR6 Graphics Card. Video of experiment results can be found through this link: https://youtu.be/Hio9urnsc14. For these experiments, the maximum twist angle is set to $\theta_{\max} = 60°$. Figure 3 presents the experimental results obtained from changing the parameters of rods' count n and radius r in the parametric kinetic spinner design. Rod shapes are obtained from square function: $f(x) = 1 - |x|$. The results are organized into a 3x3 grid. Each row represents a different rod's count n, with the first row corresponding to $n = 15$, the second row to $n = 25$, and the third row to $n = 35$. Similarly, each column represents a different rod's radius r, with the first column representing $r = 0.05$, the second column representing $r = 0.10$, and the third column representing $r = 0.15$. In each subfigure, the left part illustrates the kinetic spinner at time $t = 0$ seconds, while the right part displays the kinetic spinner at time $t = 3$ seconds. By analyzing the figure, it is evident that changing both the number of rods and their radius significantly

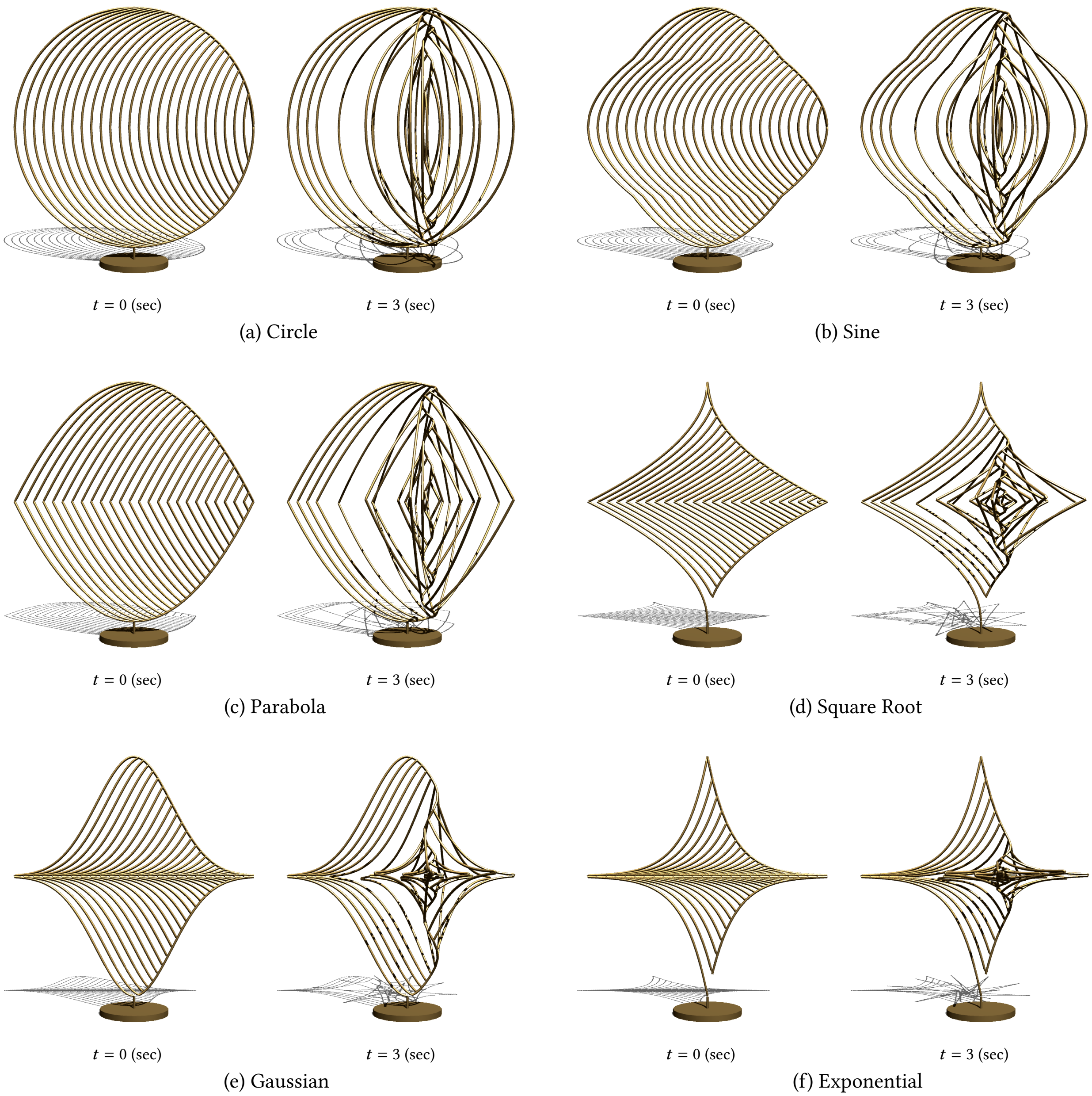


Figure 4: Changing Parametric Function. This figure shows the experiment results of changing parametric functions for shapes.

influences the overall visual effects of the kinetic spinner. These experimental findings provide valuable insights into the scalability of our approach and can be instrumental in understanding how different parameters impact the kinetic spinner's motion over time.

Figure 4 presents the experimental results of investigating the impact of different parametric functions, denoted as $f(x)$, on the shapes of rods. The rods' count is fixed at $n = 25$, and their radius is maintained at $r = 0.10$. The results are systematically organized into a 3x2 grid, where each grid showcases a distinct parametric function $y = f(x), x \in [-1, 1]$. Figure 4(a) depicts the rod shapes obtained from the circle function: $f(x) = \sin\left(\cos^{-1} x\right)$, while Figure 4(b) illustrates the shapes derived from the sine function:

$$f(x) = \begin{cases} \sin\left(\frac{\pi}{2}(|x| + 1)\right) & |x| < 0.618 \\ \frac{2}{\pi}\sin^{-1}(-|x|) + 1 & |x| \geq 0.618 \end{cases}$$

Figure 4(c) displays the rod shapes corresponding to the parabola function: $f(x) = 1 - x^2$, and Figure 4(d) portrays the shapes resulting from the square root function: $f(x) = 1 - \sqrt{1 - |x|}$. Additionally, Figure 4(e) shows the rod shapes associated with the Gaussian function: $f(x) = e^{-5x^2}$, and Figure 4(f) presents the shapes obtained from the exponential function: $f(x) = e^{-5|x|}$. By visually presenting these results, the figure provides valuable insights into how different parametric functions affect the shapes of kinetic spinner, aiding in a comprehensive understanding of underlying patterns.

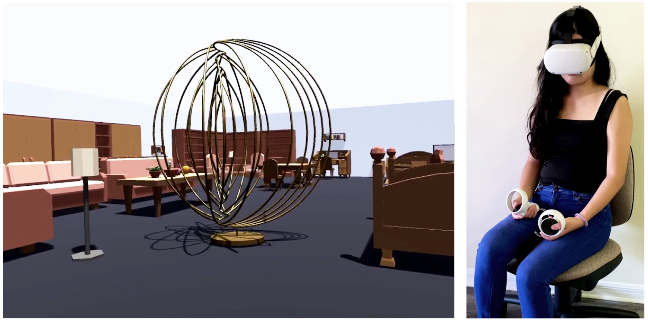


Figure 5: User Study. This figure shows the experiment of conducting a preliminary user study on watching animated parametric kinetic spinner in a virtual environment. In this experiment, through Oculus Quest 2 VR headset and VR controllers, user presents in a virtual environment and observes the kinetic spinner animated with our proposed approach.

User Study. Figure 5 depicts the process of a preliminary user study conducted to evaluate the user experience of watching animated parametric kinetic spinners within a virtual environment. During the study, seven real-time parametric kinetic spinner animations are automatically simulated in VR according to those the experiment settings specified in Figure 4. Utilizing cutting-edge technology, the experiment involves user wearing an Oculus Quest 2 VR headset equipped with VR controllers, immersing in a captivating virtual world. Within this environment, user observed mesmerizing kinetic spinners that have been generated and animated using the innovative approach proposed by us. The study aims to test the participant's reactions, engagement, and overall satisfaction with the presented animated kinetic spinner, offering valuable insights into the potential of this novel technical approach.

5 CONCLUSION

In this paper, we present a novel approach to animating parametric kinetic spinners in VR. With our approach, parametric spinners are designed using mathematical functions to define their geometric shapes. Meanwhile, integrating parametric kinetic spinners in VR environments offers new opportunities for interactive and immersive experiences. This paper discusses the design principles, implementation details, and preliminary user study, and in the end, we have validated the correctness of our proposed approach through a series of numerical and user experiment results.

In future work, the potential applications of this technology in entertainment, education, and simulation will be explored. In the realm of kinetic art edutainment, these parametric kinetic spinners can be incorporated into interactive exhibits or installations, allowing participants to explore and create mesmerizing visual patterns through hands-on manipulation. Such experiences can foster a deeper appreciation for the aesthetics of motion and the principles of kinetic art. Additionally, in the context of physics edutainment, kinetic spinners offer a tangible and engaging way to demonstrate concepts like angular momentum and rotational motion. By observing and interacting with kinetic spinners, learners can grasp fundamental physics principles with a sense of wonder and play, making the learning experience both enjoyable and enlightening.

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