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Make it swing: Fabricating personalized roly-poly toys

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ABSTRACT

A roly-poly toy is considered as one of the oldest toys in history. People, both young and old, are fascinated by its unique ability to right itself when pushed over. There exist different kinds of roly-poly toys with various shapes. Most of them share a similar bottom which is a hollow hemisphere with a weight inside. However, it is not an easy task to make an arbitrary model to swing like a roly-poly due to the delicate equilibrium condition between the center of mass of the roly-poly toy and the shape of the hemisphere. In this paper, we present a computer-aided method to help casual users design a personalized roly-poly toy and fabricate it through 3D printing with reduced material usage and sufficient stability. The effectiveness of our method is validated on various models. Our method provides a novel easy-to-use means to design an arbitrary roly-poly toy with an ordinary 3D printing machine, extricating amateurs from the dilemma of finding extra weight to balance the shape.

1. Introduction

A roly-poly toy, which is also referred to as a tumbler, is usually a round-bottomed doll. It is considered as one of the oldest toys in history. The bottom of a traditional roly-poly toy is roughly a hemisphere, so that it is able to right itself when pushed over. Over the years, different-looking roly-poly toys are produced across the world, such as animals, clowns, and celebrities. They have come to symbolize the ability to have success, overcome adversity, and recover from misfortune (Kyburz, 1994).

Traditional roly-poly toys usually consist of two parts (Wikipedia, 2016). The upper part has an amazing variety of shapes influenced by culture and manufacturers. The lower part (base part) is mostly round and roughly a hemisphere, which is generally hollow with a metal weight inside to balance the center of mass. The shape of the lower part and the center of mass of a roly-poly toy are carefully designed for regaining balance by itself. However, creating a personalized roly-poly toy is traditionally a cut-and-try process which requires moderate attempts and experiences. A key problem is to keep a delicate equilibrium between the center of mass of the toy and the shape of the lower part. Usually, a carefully selected metal weight is located in the base (vigothecarpathian, 2015; krokotak.com, 2015).

3D printing enables everybody to easily fabricate 3D models. However, making a personalized roly-poly toy is still a nontrivial process for ordinary users as the input mesh must be edited carefully to keep the equilibrium. Moreover, most 3D printers use the same material which makes it even harder to balance the roly-poly toy and make it swing.

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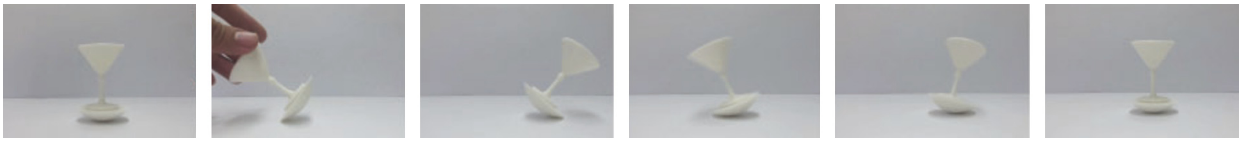

Fig. 1. A goblet shape roly-poly toy example designed by our method. The snapshots show that the toy is able to regain balance when pushed over.

Much attention has been devoted in the field of fabricating models with certain structures associated with static equilibrium and motion. Prévost et al. (2013) aimed to fabricate static models that stand in various poses. Bächer et al. (2014) took a step further to spin it. Different from previous work, in our case, the toy to be printed should balance on the initial standing position and restore to the balancing state after being pushed over or rotated. Therefore, our design will result in different equilibrium conditions and constraints for optimization in order to account for the special dynamic properties of roly-poly toys. When designing the equilibrium constraint, we should take the shape of toy, the stability of restoring balance, and the swing amplitude into consideration.

In this paper, we present a novel framework to help amateurs design personalized roly-poly toys. (See Fig. 1.) In our interactive design system, the upper part mesh of a roly-poly toy is provided by users. The input mesh is firstly optimized in terms of mass distribution. Then, a corresponding base part is calculated. Finally, the generated results are fabricated through 3D printing. Besides the reduced material usage constraint, our approach can maintain sufficient stability and attain amplitude of swing as large as possible. We have conducted extensive experiments on a variety of models to validate our pipeline, which are demonstrated in the accompanying video.

The contributions of this paper lie in the following main aspects: (i) We present a novel framework to fabricate roly-poly toys which can theoretically guarantee the stability of the printed toy. To the best of our knowledge, this is the first approach to design personalized roly-poly toys through 3D printing. (ii) We formulate the design process as an optimization problem so as to reduce the printing material and maintain dynamic characteristics of the resulting toy. (iii) We develop a method to print the whole toy with the same material without using traditional metal weight to balance the center of mass.

2. Related work

3D Printing stimulates a significant amount of research interests in the computer graphics community recently. With the help of simulation techniques, some methods have been developed to optimize 3D shapes to satisfy specific elastic deformation constraints under external forces (Bickel et al., 2010; Chen et al., 2014). Shape optimizations are introduced to reduce supporting structures and speed up the printing process (Kwok et al., 2015; Zhang et al., 2015; Hu et al., 2015). Adding 3D-printable joints provides a solution to produce functional posable models (Bächer et al., 2012; Calì et al., 2012). Mechanical motion is achieved using mechanical automata (Coros et al., 2013; Ceylan et al., 2013). Offset surfaces can also be employed to reduce printing materials by making printed objects hollow (Liu and Wang, 2011; Wang and Manocha, 2013). To optimize the mass distribution and the stability of printed objects, Musialski et al. (2015) proposed a reduced-order shape optimization method by using offset surfaces with varying thickness. In addition, surfaces with desired spatially varying reflectance can be fabricated (Lan et al., 2013; Chen et al., 2013). Different from previous methods, we provide an insight into fabrication-oriented design towards dynamic equilibrium.

Structural stability analysis under varied loading conditions plays a crucial role in printing digital models. It helps to detect the weak regions and enhance its printability through the shape optimization. Whiting et al. (2009, 2012) introduced the idea of generating structurally feasible models of buildings. They used the measure of infeasibility as an energy function and optimized the energy to satisfy structural constraints. Panozzo et al. (2013) designed unreinforced masonry models. Deuss et al. (2014) applied and extended the framework to successfully assemble self-supporting structures. To satisfy the stress constraints, Stava et al. (2012) added support structure and adjusted the thickness of the surface mesh. Zhou et al. (2013) proposed an easy-to-use framework to analyze the worst load distribution by means of a fast linear element-based method. Besides improving structural stability, we also focus on adjusting the center of mass using shape optimization.

The delicate balance between static equilibrium and dynamic motion is fascinating. The approach proposed by Prévost et al. (2013) drew researchers' attention to fabricate static models that stand in various poses without requiring glue or pedestals. Bächer et al. (2014) took a step further in dynamic equilibrium. They proposed an impressive framework to optimize the rotational stability using a combination of hollowing inside, cage-based deformation, and dual-material models. Different from them, we are interested in solving the static and dynamic equilibrium of a roly-poly toy. The process formulation, variables, and constraints involved are quite different from previous methods.

Toy design. Researchers have devoted much to the delightful design process of toy manufacturers (Mitani and Suzuki, 2004; Igarashi and Igarashi, 2009; Zhu et al., 2012; Guo et al., 2014). Puzzles with interlocking pieces are fabricated (Lo et al., 2009; Xin et al., 2011; Song et al., 2012). Mori and Igarashi (2007) introduced an interactive system to conveniently design personalized plush toys. Based on sketch interface, this system facilitates various editing operations tailored for plush toy design. Later on, 3D printing becomes an active part in toy design, especially for toys with sophisticated geometry characteristics. Hirose et al. (2011) proposed an interactive system to design the unique solid "sphericon" with additional conditions like geometric and symmetry constraints. Mueller et al. (2014) presented a layout refinement algorithm that