BalloonFAB: Digital Fabrication of Large-Scale Balloon Art

Haoran Xie
Japan Advanced Institute of Science and Technology
Ishikawa, Japan
xie@jaist.ac.jp

Yichen Peng
Japan Advanced Institute of Science and Technology
Ishikawa, Japan

Naiyun Chen
National Chiao Tung University
Hsinchu, Taiwan

Dazhao Xie
Japan Advanced Institute of Science and Technology
Ishikawa, Japan

Chia-Ming Chang
National Chiao Tung University
Hsinchu, Taiwan
chiamingchang@nctu.edu.tw

Kazunori Miyata
Japan Advanced Institute of Science and Technology
Ishikawa, Japan
miyata@jaist.ac.jp

ABSTRACT

We propose an interactive system that allows common users to build large-scale balloon art based on a spatial augmented reality solution. The proposed system provides fabrication guidance to illustrate the differences between the depth maps of the target three-dimensional shape and the current work in progress. Instead of using color gradients for depth difference, we adopt a high contrast black and

CHI'19 Extended Abstracts, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5971-9/19/05.
https://doi.org/10.1145/3290607.3312947

white projection of the numbers in considering balloon texture. In order to increase user immersion in the system, we propose a shaking animation for each projected number. Using the proposed system, the unskilled users in our case study were able to build large scale balloon art.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; Interaction devices; Graphics input devices.

KEYWORDS

balloon art; large-scale fabrication; spatial AR; projection Mapping; interactive guidance.

Figure 1: Examples of balloon art. All images are license-free.

INTRODUCTION

Balloon art has a long history of being regarded as a toy or as festival decoration. By twisting and shaping, balloons can be formed into different shapes such as animals and vehicles. As an art form, different scales and shapes of balloon creations have been produced for public and private purposes, as illustrated in Figure 1. In particular, balloon art is often utilized as decoration in celebrations and events. However, balloon art is commonly on a small scale, and it is difficult to build large-scale versions of complex three-dimensional shapes. In these cases, large-scale balloon art requires specialized skill. In addition, the making process is often tedious because hundreds of balloons are required. In order to solve these issues, we propose an interactive fabrication system to help the common user build large-scale balloon art in an easy and enjoyable way, and to help users engage with the process using spatial augmented reality techniques.

Recently, various digital fabrication techniques have been explored in both computer graphics and human-computer interaction research fields. For example, a digital system has been proposed to help sculptors using a projector to illustrate depth information on the work in progress [6]. By projecting gradient colors to show the incorrect areas, this system guides users to sculpt the expected shape. Elsewhere, a beadwork design system has been proposed for collecting beads into different 3D shapes [2]. Also, the end-to-end fabrication on physical interfaces has been explored extensively for non-experts [5]. However, all these studies explore digital fabrication on a small scale.

To build large-scale fabrications is a challenging issue because of the spatial limitations of current 3D printers and the amount of labor and materials are required. To address these issues, TrussFab has adopted plastic bottles as bricks in large scale fabrication [3], and Printflatable has proposed a fabrication system that uses inextensible thermoplastic material for human-sized inflatable objects [7]. Similar to these fabrication systems, we adopt the balloon as the raw material to achieve large-scale fabrications. In addition, this work considers user guidance throughout the fabrication processes, an

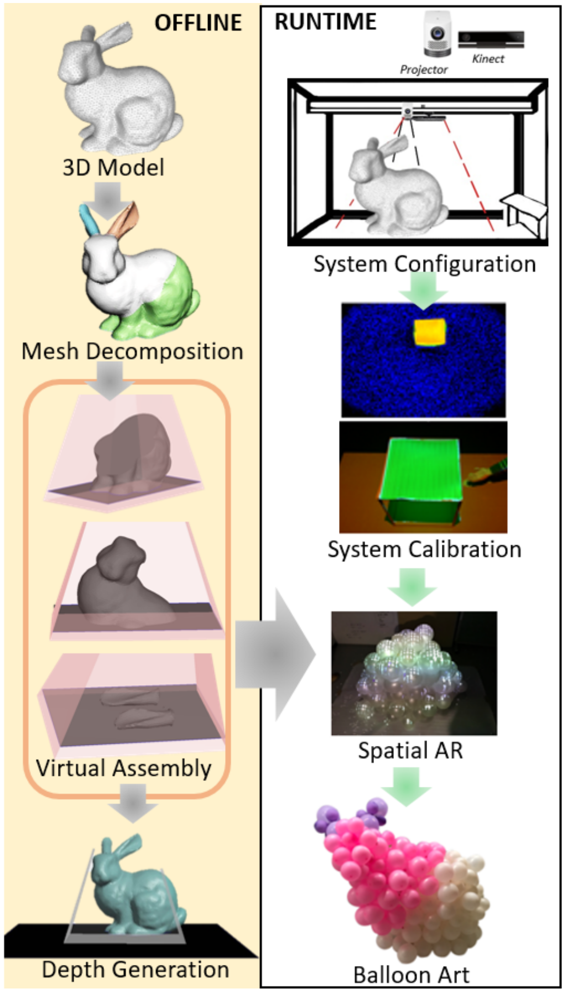

Figure 2: Proposed system framework

element which is absent in previous studies. We believe that interaction with the fabrication process can make the procedures more interesting.

In this work, we propose a design and fabrication system called BalloonFAB that allows unskilled users to build large-scale balloon art. BalloonFAB utilizes an interactive projection mapping technique in spatial augmented reality. The proposed system provides fabrication guidance for a target 3D shape by acquiring real-time depth maps using depth sensor and a target depth map using ray-triangle intersection. To build the system, we then visualize the depth differences between the target model and current work in progress. BalloonFAB provides guidance to the end user by projecting numbers on to a workspace. In addition, we design a shaking animation for each number to increase the enjoyment. In our study, multiple users were able to cooperate with enjoyment and accomplish large-scale balloon art using different colors and sizes of balloons.

SYSTEM DESCRIPTION

As illustrated in Figure 2, the framework of the BalloonFAB system includes both offline computations of the target depth map and the runtime process of interactive projection mapping with a Kinect-Projector system. In the offline computations, we first establish a virtual workspace alongside the real-world context and then we decompose the model mesh into different parts. For each part, we calculate a depth map by ray-triangle intersection Figure 3. In the runtime process, we adopt a spatial augmented reality technique for interactively projecting guidance information onto the workspace. The depth difference between the current and target depth maps is used to provide guidance to the user. The visual guidance presents images of numbers in high contrast to avoid the influence of balloon texture. Following this guidance process, all parts of the shape are fabricated by the user, and then assemble them together through further guidance relating to the whole shape.

IMPLEMENTATION

In this section, we describe the implementation details of the proposed system framework shown in Figure 2.

System setup. In our case study, we adopted the well-known complex 3D shape of the "Stanford bunny" and set the height to 150 cm for large-scale fabrication. We used a laser projector that has apparent projection image even in day light (LG HF80JG, 2000 lumen). For the depth sensor, we used a Microsoft Kinect V2 with a depth image resolution of 512×424). To inflate the balloons, we used a dual-nozzle electric air pump (AGPtek) and to connect the balloons, we used Velcro tape cut into small pieces of around 15 mm $\times$ 15 mm.

System calibrations. We calibrated the Kinect-Projector system using position matching where we measured the projection area in the workspace and calculated the size ratio and position difference

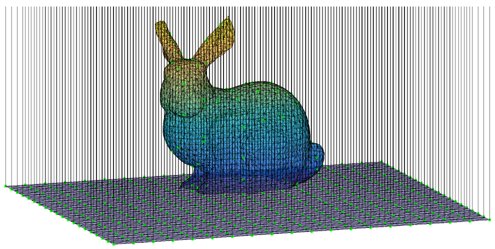

Figure 3: Ray-triangle intersection.

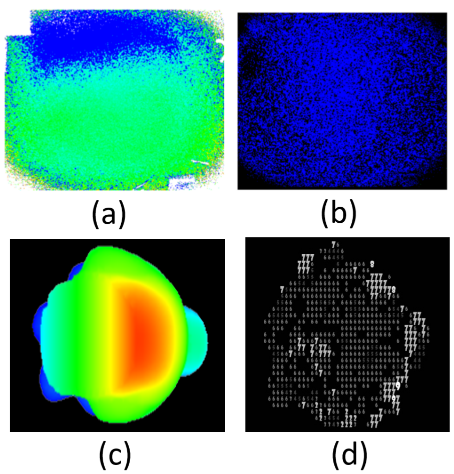

Figure 4: (a) Environment depth; (b) Corrected depth; (c) Depth difference in color gradient; (d) Fabrication guidance.

Figure 5: Projection tests on the balloons.

across a range of coordinates. The projector height was set around 2.5 m and the Kinect was set positioned close to the projector. By matching coordinates in the projection area with the Kinect space, we were able to register guidance information on the projection surface, such as the green box in Figure 2.

Depth calculation. In order to calculate the virtual depth map, we virtually located the target mesh at the area overlapped by both the projection and the depth sensor as the real world. We adopted the ray-triangle intersection algorithm as a ray tracing problem [4]. The calculation results are shown in Figure 3;the black lines denote the ray from top to bottom and the green dots represent the intersection positions. We used 512×424 rays corresponding to the resolution of the depth map. We utilized a parallel computation strategy, the cost of which was around 35 seconds for one of the target shapes.

Mesh decomposition. Projection guidance is analogous to fused deposition modeling in 3D printing where a pyramidal shape can be covered by the maximum projection area. We adopt an approximate pyramidal decomposition approach [1] to decompose the "Stanford bunny" model into four parts as shown in the offline processes of Figure 2: lower part, the upper part, and two ears.

Depth difference. To eliminate environmental errors such as floor bumps, we obtained an environment depth map using from the depth sensor without placing any obstacles Figure 4. We then subtracted this map from the current depth information to obtain the corrected depth (4b). Finally, the difference between the corrected and target depths was calculated(4c).

Fabrication guidance. In order to visualize the depth differences effectively balloon art in progress, we conducted projection tests as shown in Figure 5. In contrast to the color gradients used in previous work [6], we found that black and white projection is a better solution. We thereby utilized different numbers from 0 to 9 to represent different levels of depth difference to guide the user in whether to add or remove balloons and whether to increase or decrease the balloon size (4d). In order to enhance interactive immersion, we implemented a shaking animation on the projected numbers when the level of difference reached the higher ranges Figure 6.

USER INTERACTION

In the proposed framework, users are involved in the entire fabrication process, as illustrated in Figure 7. In the fabrication loop of building each target part, the participant first choose a balloon with his favourite color, and then inflate the balloon into the required size by the air pump. Note that the user can decide the balloon size by controlling the inflation time. Users can add or remove balloons based on the projected numbers. After one fabrication part is completed, users set it aside to build the next required fabrication part. Velcro tape is used to join the balloons, but note that the workpiece is not fixed to the ground. During assembly, users connect the different parts according to projected target

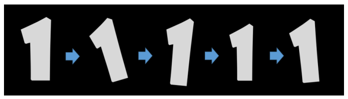

Figure 6: Images per frame in numbers shaking animation design.

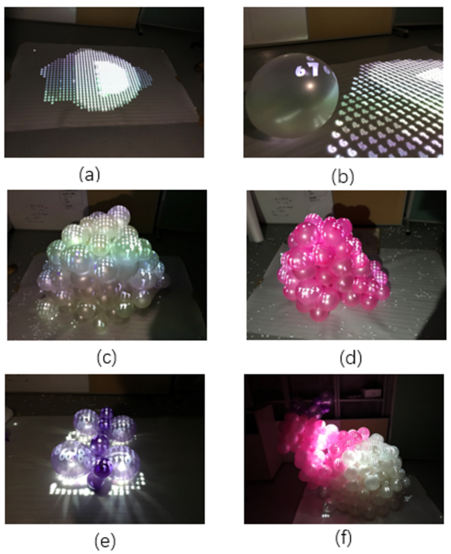

Figure 8: (a) shows our guidance system with empty work space. (b) shows our system when balloon placed.(c)-(f) shows the fabricated parts and their assembly.

depth maps of the entire 3D shape. Although this projection area can not cover the entire model, we observed that the connection interfaces between fabricated parts are covered in the projection area.

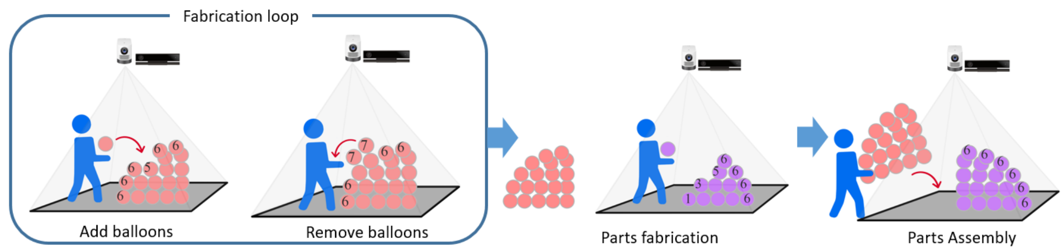

Figure 7: User interaction in the proposed fabrication process.

RESULTS

Three male graduate student participants were asked to produce the balloon art using the proposed system. The total time cost was around 3.5 hours; 178 balloons and 8.5 meters of Velcro tapes were used. Different from previous work that used colors gradients [6], we impemented a black background with white text which proved more readable and suitable for the different surface textures of the balloons. In addition, we designed shaking numbers for large differences in depth which was more likely to increase the users' enjoyment as shown in Figure 8. Figure 9 presents the fabrication results. Following the outcome of the mesh decomposition, the process involved making the lower and upper parts and the two ears, and then assembling them as one. Each stage of the process utilized projected guidance using the depth maps developed during the offline computations. According to participant feedback, the proposed BalloonFAB system made the fabrication process an enjoyable experience.

Reflection. From this study, we received both positive and negative feedback from the participants. On the positive side, participants were able to see the projected numbers. Through the use of the shaking animation, high differences became quite apparent. On the negative side, it is hard to achieve flat surface with balloons, and assembling the fabricated parts became inaccurate due to uneven connection surfaces. In addition, it was difficult to build smaller elements, such as the bunny ears, because of the limited sizes range of the available balloons. From a technical perspective, we consider that our proposed system may lose geometric accuracy in balloons under around 15 cm. However, user can adopt our system to create balloon art for entertainment purposes. In the case of balloon sculptures requiring good accuracy, elongated balloons should be considered as fabrication elements in future study.

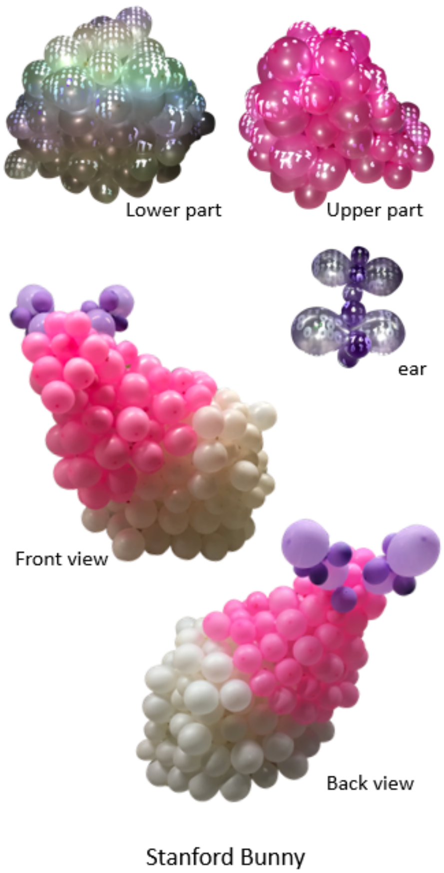

Figure 9: Fabrication results using our proposed system.

CONCLUSION

In this work, we have proposed a system called BalloonFAB for the creation of large-scale balloon art creation. As opposed to previous work that has used color gradients in guidance projections, we adopted a high-contrast scheme. In addition, the shaking animation of the projected numbers made the proposed system enjoyable to use. In our case study, we found our balloon art fabrication system can even be used for producing complex shapes. In future work, a multiple projection system may be a better solution to cover all building surfaces, and we will also consider fine detail in these future studies, for example, through using the elongated balloons that are commonly used by balloon art experts.

ACKNOWLEDGMENTS

This work is supported by JSPS KAKENHI grant JP17H06574, Japan and Higher Education Sprout Project grant 107-2200-001, Ministry of Education, Taiwan.

REFERENCES

[1] Ruizhen Hu, Honghua Li, Hao Zhang, and Daniel Cohen-Or. 2014. Approximate Pyramidal Shape Decomposition. *ACM Trans. Graph.* 33, 6, Article 213 (Nov. 2014), 12 pages. https://doi.org/10.1145/2661229.2661244

[2] Yuki Igarashi, Takeo Igarashi, and Jun Mitani. 2012. Beady: Interactive Beadwork Design and Construction. *ACM Trans. Graph.* 31, 4, Article 49 (July 2012), 9 pages. https://doi.org/10.1145/2185520.2185545

[3] Robert Kovacs, Anna Seufert, Ludwig Wall, Hsiang-Ting Chen, Florian Meinel, Willi Müller, Sijing You, Maximilian Brehm, Jonathan Striebel, Yannis Kommana, Alexander Popiak, Thomas Bläsius, and Patrick Baudisch. 2017. TrussFab: Fabricating Sturdy Large-Scale Structures on Desktop 3D Printers. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 2606–2616. https://doi.org/10.1145/3025453.3026016

[4] Tomas Moller and Ben Trumbore. 1997. Fast, Minimum Storage Ray-triangle Intersection. *J. Graph. Tools* 2, 1 (Oct. 1997), 21–28. https://doi.org/10.1080/10867651.1997.10487468

[5] Raf Ramakers, Fraser Anderson, Tovi Grossman, and George Fitzmaurice. 2016. RetroFab: A Design Tool for Retrofitting Physical Interfaces Using Actuators, Sensors and 3D Printing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 409–419. https://doi.org/10.1145/2858036.2858485

[6] Alec Rivers, Andrew Adams, and Frédo Durand. 2012. Sculpting by Numbers. *ACM Trans. Graph.* 31, 6, Article 157 (Nov. 2012), 7 pages. https://doi.org/10.1145/2366145.2366176

[7] Harpreet Sareen, Udayan Umapathi, Patrick Shin, Yasuaki Kakehi, Jifei Ou, Hiroshi Ishii, and Pattie Maes. 2017. Printflatables: Printing Human-Scale, Functional and Dynamic Inflatable Objects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 3669–3680. https://doi.org/10.1145/3025453.3025898