StoryCube: Supporting Children's Storytelling with a Tangible Tool

Abstract Storytelling is one of the effective methods used in education. Computer-aided storytelling allows children to create more free-form stories and provides a large amount of story materials. Grounded in the current related works, we propose and design a tangible interactive tool, which supports children to interact with virtual objects via a tangible way instead of the usage of mouse/keyboard. With this tool, we also develop a system called StoryCube where children are able to create a 3D story environment and accomplish story narrations through physical manipulations to different virtual characters. From a preliminary user study, we find StoryCube full of playfulness, easy to learn and use, and somehow inspire children in storytelling activities.

Keywords *Children, Storytelling, Tangible user interface, Sensor, User study*

TUI: Tangible User Interface

1 Introduction

Storytelling is a traditional way to convey values, knowledge and beliefs and help children know about the world [8]. Meanwhile, it plays a significant role in children's development, especially in building their social and cognitive areas [13]. Storytelling enhances children's expression, logical thinking, imagination and creativity [4]. Besides, it contributes in problem solving, communication and cooperative skills within children.

As an interdisciplinary research field, storytelling draws increasing attention of researchers from various fields around the world, even though the significance of traditional narrative tools has been recognized. Since the late of 20th century, some researchers had begun to focus on exploring interactive storytelling with computers thanks to the rapid development of personal computer, including creating interactive stories, conceiving flexible story contexts and designing a decision-making process for dynamic casual outcomes of stories [26]. Compared with traditionally linear and conversation based structure, interactive storytelling not only brings more variations (plots or outcomes) in developing stories, but also gives storytellers more free room for imagination and creativity [24].

Recently a fair amount of remarkable works on children's storytelling have been achieved [3, 9, 10, 12, 18] and they actually bring good storytelling experience to children. In these works mouse and keyboard are widely used in tabletop interaction. Dragging items across the screen is a common requirement in graphical user interface but may be problematic for young children whose coordination is not yet fully developed [5]. Timothy analyzed some physical interfaces and drew a conclusion that electronic toys help children develop advanced modes of thinking through free-form play [27]. He suggests that Tangible User Interfaces (TUIs) make computation immediate and more accessible. Besides, they are appropriate for children to explore computation and scientific thinking [27]. The physical environment can encourage children to construct things, to turn abstract concepts into concrete objects, and to collaborate [12]. Compared with traditional peripheral I/O devices, physical objects are more familiar and easier to children [14]. Tangible interface and interaction somehow are of benefit in the development of children's cognition and study [2]. Therefore, tangible interface can be a good way to support storytelling, though many deficiencies still exist in existing tangible systems [12] such as inflexible environment and tools which constrain children's imagination and creativity.

Considering the familiarity of physical objects in tangible interfaces and plentiful multimedia resources provided by computer, this paper takes both advantages of tangible interaction and tabletop storytelling system, and this approach makes story creation and leaves them more efficient and simpler for children and leaving them more opportunities to free imagine. In this paper, we will introduce a storytelling system StoryCube, which contains a tangible tool allowing children to alter and operate virtual objects on screen and a 3D storytelling system presenting and augmenting story. Our targeted children are aged from 5 to 8 years old. StoryCube enables them to pick story elements and characters, to decorate their own story scene, and to design unique story plot. When telling a story children are able to decide how the story develops through direct manipulation on the tangible tool as if they are playing with toys in daily life. The structure of the paper is as follows. The second section introduces some related works and literatures that our work is mainly based on. The third part mainly describes the design and implementation of StoryCube. Then the fourth part presents the preliminary user study we conduct and discusses about some conclusions we draw from observation. In the end, we address the next step on our work and make some summary about this paper.

2 Related works

Tangible User Interface can be defined as everyday objects or environments that augment the physical world by being coupled to digital information [15]. The technology of TUI could be introduced into children's creative activities, for example, storytelling. The article of McNerney discussed some of the results of physical interfaces research: electronic toys that help children develop advanced modes of thinking through free-form play [27]. He suggested that TUIs make computation immediate and more accessible, and that they are appropriate for children learning about computation and scientific exploration. The physical environments encourage children to construct things, to turn abstract concepts into concrete objects, and to collaborate [18]. StoryMat [9] is one good example. It is a large quilt with small stuffed animals that enables children to construct and retell stories through interactions with the toys and quilt. The adoption of toys is a good idea for children's interaction but the bespoke quilt dramatically limits the content of the story children build. Similarly, TellTale and TOK both are systems that only allow children to alter stories through physical objects under certain conditions. The TellTale system used a modular toy to support children's oral storytelling. Children could record and reconfigure their own stories by rearranging the physical segments of the toy [1]. In TOK system children created stories by placing and rearranging cards on which pictures represent different episodes of a predefined story. These systems provide touchable and tactile interfaces which is a salient advantage of TUIs [22]. However, these bespoke systems get children away from original creativity. StoryRooms [18] is one typical exponent of encouraging children design and create stories on their own. In StoryRooms, children as designers could define the semantic of story elements with iconic objects and organize them to construct a complete story. In this process children were able to control everything about the story and tangible tools with sensors, which were components to support children's design. Another system named ToonTastic [19] is also designed to encourage young children to create their own cartoons and share their stories.

Many other systems also take a novel and flexible approach to connect real world with children's creative activities, including OnObject [11] proposed by MIT, which is a device that triggers one possible episode of a story when encounters specific events defined by gestures and records the whole story narrated by storyteller, JabberStamp [21], which provides children with a canvas to freely create scene and characters via the way of drawing, PuzzleTale [26], which integrates puzzle game into storytelling and makes different stories by meeting different roles, and Picture This! [28], which brings a novel approach of camera in story creation. The idea of camera person makes it a process of film making. To enrich the resources for tangible systems, I/O Brush [20] picks up colors, textures and movements found in everyday objects and permits storytelling on screen through drawing. Moreover, TellTable [6] developed by Xiang is a framework which allows children to collaborate in devising stories that mix the physical and the digital in creative ways and that could include themselves as characters on the multi touch interactive table. These systems put emphasis on the concept of borrowing attributes from real world for storytelling.

According to the works discussed above, TUIs are appropriate in children's storytelling, whereas general immutability of physical objects give rise to less scalability in various contexts. Adversely, Graphic User Interface (GUI) is capable to give a more flexible way to present information and data timely under different circumstances. For instance, KidPad [12] provides a tool for children to paint stories in a large 2D and zoomable environment. It is the graphic interface that presents more multimedia resources in a limited space. Alice system [10] developed by MIT provides a 3D graphic environment to render the story stage and it is proved more attractive among other storytelling systems.

Since TUIs and GUIs both have their own good sides, a lot of researchers begin to combine them together and design systems with mixed technologies. Marc Cavazza et al. [7] developed an immersive interactive storytelling system composed of a CAVE-like system, allowing users to communicate with a 3D animation by postures and voice in virtual surroundings. Another system named Tangible Comics [23] is a full-body interactive storytelling environment based on computer vision technology. Apart from interactions between physical body and virtual objects, GENTORO [25] makes several robots play their own stories in a physical space augmented by mixed reality technologies. Due to camera or projector used in most of these systems, ambient light has great impact on the effect of such mixed-reality systems. Besides mixed reality, researchers have delved into interactive tabletop applications. Like TellTable mentioned before, RoboTable [17] is an interactive tabletop system that enables users to naturally and intuitively manipulate robots and presents virtual information on the surface of the table. Such systems limit users' behavior within the edges of the table and they are expensive. Others adopt physical models and visual feedback to build an interactive environment for children's storytelling, such as PageCraft [16], a 3D system where computer knows what physical object children are dealing with and record children's narrative. PageCraft puts forwards an inspiring solution in combining TUIs and GUIs properly though the models in PageCraft are quite not easy to make for children.

Our aim with StoryCube is to design a tangible tool that provides a familiar and convenient way to help children in storytelling and reduces children's cognitive load, and to develop a 3D environment based on our previous work [29] that provides multiple story materials for storytelling and less constraints for free imagination and creation. It shares many aspects with the systems already described: like PageCraft, it gives proper visual feedback on screen, like Alice, it shows how attractive a 3D system is to children, like StoryMat, toys can be directly used in storytelling, and like many of the above. However, StoryCube avoids disadvantages of those systems and provides a more scalable platform which enables children to focus on the creation of stories. Children have no need to change or reconfigure the tangible part when new toys or models are added in the system, which is a common deficiency in other tangible systems. The following part we will detail the StoryCube system.

3 StoryCube system

3.1 Design goals

StoryCube is a storytelling system to support children in composing stories creatively and conveniently with a tangible tool and viewing stories timely in a 3D story environment on the screen. Children are able to decide what element should appear in the story and control virtual characters easily by physical manipulations on the tangible tool. Additionally, the 3D story world provides visual feedback on screen immediately. In this system we were guided by the following design goals:

Novelty and playfulness: With children as target user, the primary goal for StoryCube is to attract children to tell stories. We hope to design a system which children are interested in and willing to create stories with.

Simplicity and easy-to-use: Instead of dragging mouse or typing keyboard, we hope to provide an easier way for children to compose stories with less cognitive burden and without high motor ability.

Direct manipulation and immediate visual feedback: Since children are dealing with a physical object in StoryCube, we hope to provide direct manipulation to children's movement and give back immediate feedback on screen, which would tell children the state of the system.

Encouraging free imagination and expression: In StoryCube we aim to allow children freely imagine and draw inspiration from the resources StoryCube provides. Although children are to some extent restricted by the system design, we try to separate every module and component to avoid interrupting the process of children's design and creation. Furthermore, children are encouraged to speak freely in composing stories.

3.2 The structure of StoryCube

StoryCube contains two parts: a tangible tool and a 3D virtual storytelling environment.

The tangible device is an interactive tool by which children can set story world and choose story elements. Data is captured and delivered to the computer through wires. In the computer, a virtual 3D storytelling program runs for accepting the data and dispatching them in different functions. The architecture of the system is as Figure 1 shows.

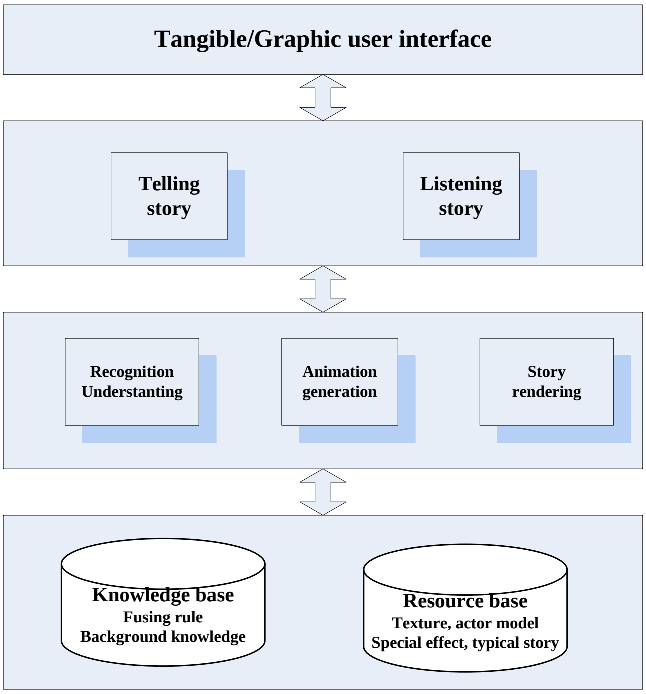

Fig. 1 Architecture of StoryCube

3.3 Tangible interactive tool

The tangible tool integrates all hardware and functional modules into a yellow cubic box, which is made up of harmless PVC boards. On the upper side of the box children are able to press seven buttons and control one joystick to accomplish story scene building, element selection and character selection. The handles on both left and right sides indicate clearly that children can grip them to move the box in any directions. In addition, we paste both ends of an elastic band firmly on left and right sides so that toys can be tied with StoryCube right in the front of the box.

Inside the box, a RFID reader is fixed in the front so that characters could be recognized when toys are tied with the box. A 3-axis accelerometer is set on the bottom to collect motion data. All the buttons, joystick and accelerometer are connected to Arduino controllers while the RFID reader is connected to an adapter. Since controllers and adapter are connected to computer through USB cables, we bound these cables together and led them out through a hole on the back of the box. Figure 2 shows the overall design and structure of StoryCube.

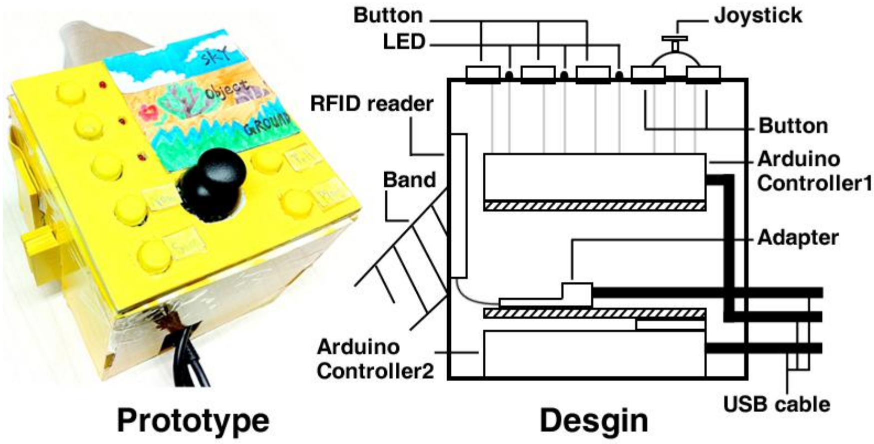

Fig. 2 The design and structure of tangible interactive tool

3.3.1 Buttons and joystick

Considering that altering some elements of story (e.g. sky, ground, and etc.) cannot be completed in a physical story environment and the fact that a story might need diverse elements, we decide to select multiple virtual resources by directly pressing buttons and moving joystick. We prepare buttons with one-click manipulation to select story elements and joystick for navigation. On the upper side of the yellow tangible box seven buttons are divided into two groups: element selection buttons and system command buttons. Element selection buttons are used to help children select story elements, in this case sky, ground and objects. We also paste pictures with text near the buttons to tell children the buttons' meaning and set LED lights to indicate what kind of element is being selected. System command buttons represent four commands: create a new story, save the story, start to tell a story and replay saved stories.

Joystick is used to navigate in the story scene by default. Together with the element selection buttons, children can move the joystick left and right to choose the right virtual resource they want on screen, for example, children can move joystick to change the style of sky after pressing the "Sky" selection button. Figure 3 shows the buttons and the joystick.

Fig. 3 Buttons and joystick on the yellow box

Currently a wide range of preset resources are provided for children. If a new resource is imported into the system, there is no need to change the physical configuration. It achieves a high scalability.

3.3.2 RFID tags and reader

Considering RFID is low-cost and easy to use in various contexts, we allow children to accomplish the mapping between the virtual characters and real objects by pasting defined RFID tags onto cards with animal picture or plush toys. Afterwards, when the card or the toy is set in the front of the tangible box, RFID reader inside the box would detect the tag and recognize what character is under control. System has prepared massive character models for children. However, we have mapped five toys to system characters. The configuration of mapping new characters is quite easy, which only needs children to allot new RFID tags to new cards or toys.

3.3.3 3-axis accelerometer

During design phase, we observed about 15 children aged from 5 to 8 who live in the neighborhood. From the observation, we found that most children are likely to move toys around them to tell stories, especially change toys from one point to another to represent the movement of story characters. We apply this pattern in designing our system. For the sake of allowing children to physically touch and manipulate the story characters directly, we adapt a 3-axis accelerometer to collect the data generated by physical motion. Theoretically we expect children to move the box flatly. However, in practice children would like to move it in space. Therefore, we take a simple coordinate transformation method in processing the raw data. Since XY plane parallels with the horizontal ground and the final direction a character walks in depends on the actual direction on XY plane, we can ignore the influence of the data of Z axis. As a result, the processed data indicates what direction character moves in.

3.4 A 3D virtual environment

To stimulate the imagination of children and augment the space of reality, we also develop a storytelling environment, where every object is rendered from OpenGL library. The virtual story environment provides a wider vision than the physical world dose for children. It has prepared a lot of 3D story resources. The resources in current system are divided into three categories: sky, ground and objects. Each category has more than ten models. It provides not only various 3D story elements but also immediate visual feedback to children's operations, for example, when the child adds a blue sky by operating the "Sky" selection button and joystick, a virtual blue sky would appear at once. When the child moves the box with a Teddy bear tied forward, the virtual bear in the system would walk forward. In addition, system records story narrative and replays saved stories so that children are able to store stories for later review. Figure 4 shows what the virtual environment looks like.

Fig. 4 The 3D virtual story environment

Along with the 3D system, we also provide auxiliary software to make more 3D objects or characters. The software is a GUI based platform where users can create various objects easily by dragging and clicking controls. In most cases, parents or teachers accomplish adding more elements by this tool instead of children themselves.

3.5 Usage scenario

Following the design goals we hope our tangible interface simple and intuitive to children. In order to lead children to finish a complete story correctly, in StoryCube we divide the process of storytelling into two modes: telling mode and listening mode.

3.5.1 Telling mode

In this mode, children can set up their own story environment. Firstly, press the "New Story" button to create a new blank story. Press the "Sky" selection button and the default sky shows up. The LED light beside the "Sky" button begins to flash. Through moving the joystick left and right children can change different skies. With similar operations, children can change the ground. When sky and ground are both confirmed, children can add some objects to the story stage, such as trees, flowers and so on, by pressing the "Objects" button. At the bottom of the screen it shows the default object - flower. Then move the joystick left and right to change objects and press the joystick to render the selected object in the middle of the story scene. Furthermore, by default children are able to navigate the virtual environment by moving the joystick left and right, forward and backward.

Here we present an example, "Hide and Seek Game" story, for assisting to explain how to use StoryCube. In the story, the storyteller presses buttons and moves joystick to create a story world, including blue sky, green grassland, two trees, several flowers and a windmill (see the left of Figure 5).

After creating the story scene, children can attach a picture card or a plush toy with RFID tag representing the character in the front of the box. At the same time the according character would appear on the screen. Children can set the virtual characters anywhere in the environment by moving the box. After every movement of the box, the character would shift from one point to another point according to the movement without any delay. When everything is ready, children can rehearse the whole story till they press the "Tell" button, which means they are ready to tell a story. When telling a story, children's movements and voice would be recorded. Under this circumstance, the controlled character would walk with an animation when children move the box. When the animation is playing children have plenty of time to narrate and organize the content. After finishing a story, children would save the story by pressing the "Save" button.

In the "Hide and Seek Game" story, the storyteller adds two roles in the story: dog and cat. Then he moves the box to the left with cat character selected. The virtual cat rendered by 3D will move in the same direction. The distance of the virtual rabbit's movement depends on the speed of the cube. The faster the storyteller moves the box, the longer distance the virtual character would move in. The right of Figure 5 shows the storyteller is telling "Hide and Seek Game".

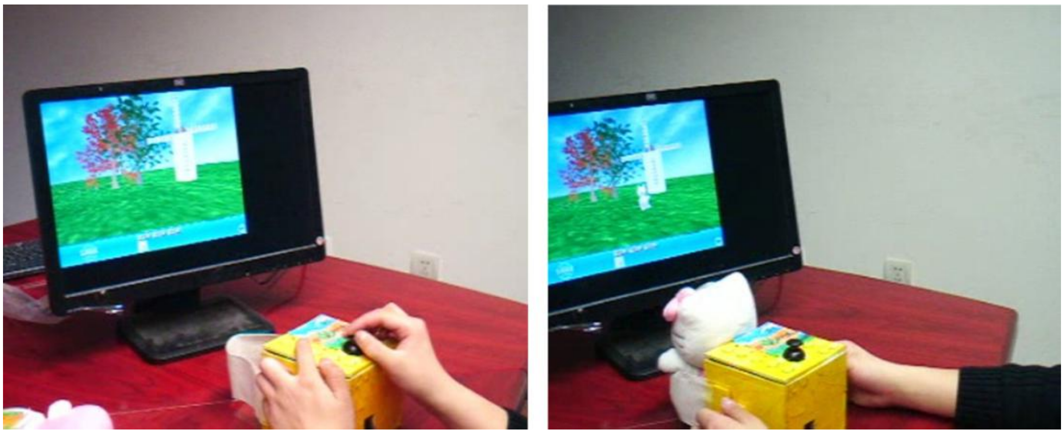

Fig. 5 Telling stories with StoryCube

Press "Replay" button and children can replay the saved stories. In our example, storyteller moves the box to decide the story roles where to go and tells what happens when the dog and the cat are playing hide and seek game.

3.5.2 Listening mode

In StoryCube children are allowed to review all the stories created by StoryCube. We present a list of stories which are created by children before and children can select one story for replay. Press "Play" button and the selected story would be replayed automatically.

4 Preliminary user study

4.1 Experiment process

In order to know how StoryCube performs we conducted a preliminary user study. We invited 8 children (5 girls and 3 boys aged from 5 to 8) living in the near community to participate in our user study. Since the experiment was conducted in the lab environment, we prepared some plush toys on the spot to make them feel at home as quickly as possible. During the user study, we recorded the whole process and observed the behaviors of children.

Firstly, an experimenter taught children how to interact with StoryCube including operations of buttons and joystick, setting story scene, selecting characters and telling a story. It lasted about 5 minutes. In this session, children were allowed to raise any questions. Before the experiment children were asked to spend time playing and practicing with StoryCube. In this session each child had to get familiar with every operation and learn how to select elements, map toys and move characters independently. The experimenter could help children when they encountered any obstacles.

In the experiment, every child was given two assignments: accomplishing the story of “The Race between Tortoise and Rabbit” and creating a free-form story. Every child had to decide the story scene, elements, characters and plot independently according to the main idea of the story. All problems except for unrecoverable errors must be overcome by themselves in this session.

Fig. 6 A child is setting story scene in the experiment

Finally, after finishing the assignments, children were interviewed by one experimenter. The interview covered some open-end question mainly about usability issues and their previous storytelling experience in their daily life. To get a better understanding of their feelings about StoryCube, we asked every child to draw the scene where they told stories with StoryCube after interview.

4.3 Analysis and results

During the user study, two video camera (fixed and mobile) and three experimenters (one was for tutorials, one was for taking notes and observing children's behavior and another was for taking photos) were assigned. The average experiment time for each child was about 25 minutes, including tutorials, free practice, assignments, interview and drawing. In the experiment, we recorded how long it took for each child to accomplish given story and free-form story respectively, wrote down what kind of operation confused them, and observed how children behaved when playing with StoryCube. Afterwards, we spent some time watching and analyzing the video about children's interactions with StoryCube, organizing and analyzing the notes of observation and encoding the pictures they drew. In encoding pictures, we regarded smile face, bright color and fluent lines as positive feeling while serious face, monochromic color and influent lines as negative feelings.

From the video and observation we found that all children accomplished the story of "The Race between Tortoise and Rabbit" in average three minutes. Six out of eight children finished a free-form story and with the further interviews we got to know that the other two children were not interested in storytelling utterly. On the other side, the average time spent on creating a free-form story is about five minutes. After decoding the pictures, we found four children used colorful brushes and five out of seven (one of the two children who were not interested in storytelling refused to paint) children drew smiling faces. Interestingly, we found a shy girl drew nothing but the yellow tangible box with details. With above results we can draw some conclusions:

Novel and playfulness: Children liked to try every interaction with StoryCube, especially buttons and joystick. From observation, we found that children frequently pressed buttons and moved joystick to select and replace story elements at both configuration mode and narration mode. In the interview, we got to know the storytelling experience of most of children was to read storybooks or tell stories without any tools to their parents. StoryCube gave them a novel experience to tell stories and they are fond of this form. They liked most to press buttons and move joystick to select virtual objects and moved the real plush toys (in experiment they attach toys on the box) when storytelling. What's more, the drawing showed children had a good impression to StoryCube and remembered details.

Simple and easy to learn: In the free play session, eight children spent average less than five minutes and the least is about two minutes. In practice most of children could understand how to interact with StoryCube but three children were confused about character selection. Two of them tried to paste two cards together to control two different characters at one time. It revealed a major drawback – the confliction of multiple RFID tags. In experiment session, all children could overcome difficulties without the help of experimenters.

Direct and immediate: No matter when setting story world, selecting elements or operating characters, children were observed used to move the box with both hands staring at the screen to expect the result. Each child seldom detracted attention from screen to the box. Statistically, children are interrupted one or two times in the activity. In most cases, they would like to think about how to tell the story but not to be disturbed by the tangible tool. From the interview we knew that the design of direct manipulation and immediate visual feedback made StoryCube not intrusive and let children know everything in the story world at any time.

Free imagination and expression: When telling the given story, all children were able to build story scene, set more than three types of objects, select multiple characters and narrate the whole plot. Though the main plot of the story is given, each child actually did some modifications, e.g. one girl added a bear as the judge of the race competition. When creating free-form stories, children preferred to add more characters, make the story more complicated, frequently change story scene elements such as the weather and move the box while storytelling. Most of them could create a totally new and imaginary story with a complete story plot. Additionally, we found that girls spent more time on telling a story than boys and the length of the story was generally longer. The further interview told us girls were less acquainted with the interactions with computers than boys and they paid more attention on the quality and details of the story.

4.4 Discussion

The preliminary user study proved that StoryCube performs well in children's storytelling. It is fun, easy and allows children to freely imagine and express in storytelling. In summary, we achieved our design goals. However, several drawbacks are found in the user study.

Since all sensors and interactive modules are connected to computer with USB cables, the cables have an impact on the movement of the box in StoryCube. Some movements are hindered because of the cables. Besides, children are likely to rotate the box when moving the characters, which result in incorrect direction detected because 3-axis accelerometer cannot detect the angle of the rotation. More attributes of each character are suggested. The general feedback from children is that characters are lack of their motions and props. The confliction of RFID should also be taken into account and other solutions could be considered to realize multiple characters interacting with each other simultaneously. In a normal story, controlling one toy every time seems not convenient enough. On some occasions, it would be better if children could operate multiple characters at one time. Children always look at their audience when telling a story to feel whether their narrative is good or not. Thus providing more emotional feedback is also necessary.

5 Conclusion and future work

This paper describes StoryCube, which contains a tangible tool and a 3D story world designed for children's storytelling. It combines both advantages of tangible interface and multimedia resources in computer, and provides a novel experience for children. A preliminary user study indicates that StoryCube is fun and easy in storytelling among children aged from 5 to 8. In addition, it also enhances children's engagement with their stories and their creativity and imagination.

The user study reveals several drawbacks. Our next step is to focus on five aspects: *customize hardware.* Admittedly StoryCube is still a prototype and more works are needed in the design of the hardware. It calls for smaller circuit, wireless connectivity and more sensors with more functionality and higher accuracy and scalability; *enrich character's props.* We decide to capture user's gestures and map them to story roles' different props; *support simultaneous interaction.* More StoryCubes are needed for multiple children to accomplish a story together; and c*onduct a formal user evaluation:* Though we have conducted preliminary user study and got some good results, several drawbacks are revealed.

The improved system needs more formal user evaluations to dig out more usability issues.

Acknowledgments

This research is supported by the National Natural Science Foundation of China under Grant No. 60970090 and No. 61272325, the Major State Basic Research Development Program of China (973 Program) under Grant No. 2013CB328805, the Frontier Project of the Knowledge Innovation of Chinese Academy of Sciences under Grant No. ISCAS 2009-QY03 and the cooperation projects of Guangdong Province and Chinese Academy of Sciences under Grant No.2011B090300086. We would like to acknowledge the support of Keqin Dou, Tianyuan Gu, Tingting Wang, Muyan Li, Yang Zhang and Yi Ren. We thank Jie Zhang and Jie Li for their excellent previous work. We thank the teachers and students in Kindergarten of Chinese Academy of Sciences for their cooperation and the reviewers for their constructive comments.

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