Puppet Narrator: utilizing motion sensing technology in storytelling for young children

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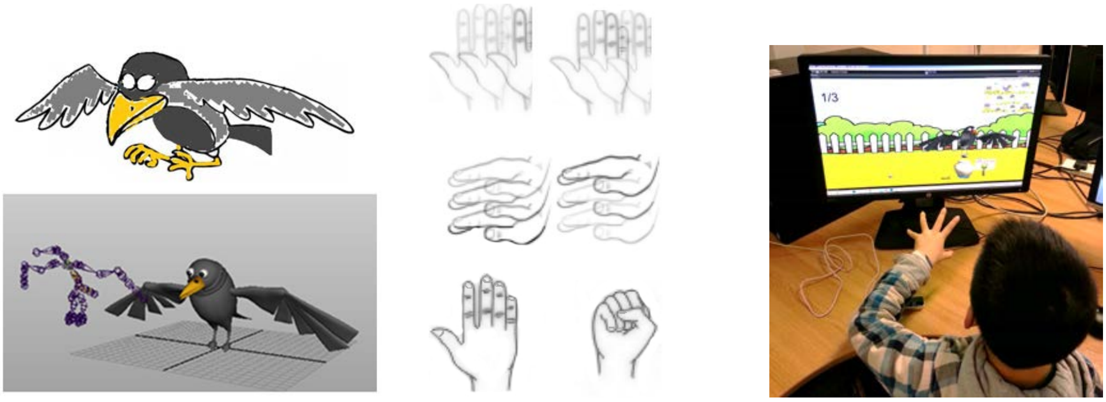

(a) (b) (c)

Fig. 1. (a) puppet crow sketch model and its 3D avatar; (b) hand gestures; (c) use hand gestures to control crow

***Abstract*— Using avatars in storytelling to assist narration has proved to be beneficial on promoting creativity, collaboration and intimacy among young children. Development of novel Human Computer Interaction (HCI) techniques provides us with new possibilities to explore the training aspects of storytelling by creating new ways of interaction. In this paper, we design and develop a novel digital puppetry storytelling system - Puppet Narrator for young children, utilizing depth motion sensing technology as the HCI method. More than merely allowing children to narrate orally, our system allows them to use hand gestures to play with a virtual puppet and manipulate it to interact with virtual items in virtual environment to assist narration. Under this novel pattern of interaction, children's narrative ability can be trained and the competencies of cognition and motor coordination can also be nourished.**

Keywords*— *Serious game; digital storytelling; virtual puppet; hand gesture recognizing; children's ability training

I. Introduction

In recognition for their considerable positive effects on pedagogy, educational games or serious games for training purposes have become immensely popular [1-2]. As a modern form of traditional storytelling, digital storytelling systems emerged over the last few years and have demonstrated powerful pedagogical functions, which enable children to express themselves and cooperate with others during narrating performance. Storytelling is essentially one of the original forms of teaching [3], which can be used as a method to teach ethics, values, and cultural norms and differences. Digital storytelling following the same well-known strategies similar to classical storytelling can help children to acquire several technological skills and work in groups and strengthen the bonds between each other. As another social benefit, digital storytelling can also help disabled children or students with learning difficulties to remove the barriers of communication with adults and peers and overcome the inability to focus on their feelings or thoughts by providing them with opportunities to play active roles [4]. At present, the major pedagogical benefit gained with digital storytelling is the ability to narrate [5-6].

However, storytelling is not just about narrative. In its basic form, storytelling is usually combined with gestures and expressions. Oral narrative can also be combined with other body movement, e.g. dancing to enhance the storytelling through remembrance and dramatic enactment of stories [7]. From this point of view, storytelling will not only benefit understanding narrative structures but also fertilize other abilities, such as cognitive competence and physical coordination during performance with the aid of different media.

The development of novel Human Computer Interaction (HCI) methods (e.g. depth motion sensing technology) provide us with new possibility for deriving storytelling's educational benefits by creating new ways of enabling interaction through hand gestures or other modalities. Since oral narrative is not the only thing that matters in storytelling, children's other capacities is also expected to increase during their storytelling

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performance, such as cognitive competence and physical coordination etc., especially when digital storytelling system could provide players more immersive interactions, such as using hand gestures to manipulate avatars to perform in virtual environments. Considering puppetry's positive benefits in education, we also study an interactive digital puppet model which works as a virtual actor to assist children's performance, as shown in Figure 1(c).

In this paper, we design and develop a novel digital puppetry storytelling system-Puppet Narrator for young children utilizing depth motion sensing technology which supports hand and finger motions as input but requiring no hand contact or touching. Considering a puppet's operation complexity for young children, we use hand tracking and gesture recognition technologies to simplify operations and provide intuitive interface, in which children can use hand gestures to manipulate virtual puppet to perform story. And different from precious research [8], in addition to narrative fertilization, we also devote to increase children's abilities on the aspects of cognitive development, and motor coordination ability during their storytelling performance with the help of depth motion sensing device.

In summary, this work has two main contributions:

- Introduce a novel narrative assistance with gesture control and computer animation by combining motion sensing technology to manipulating 3D puppet;
- Implement a prototype of the digital storytelling system to help young children to develop their related skills.

The remainder of this paper is organized as follows. Section 2 presents our system design. Section 3 describes system implementation including the architecture, input data processing, motion control, and output. Section 4 presents the examples and results. Discussion in Section 5 follows and Section 6 concludes the paper.

II. General Design

In this section we discuss the system design which involves the novel manifestation pattern as well as the pedagogical considerations we mentioned previously.

A. Target

Recently, there has been substantial amount of research undertaken on digital storytelling mainly investigating narrative abilities training, such as Toontastic, Kodu, Storytelling Alice, Wayang Authoring, et al [8]. However, as we mentioned before, storytelling is not just narrating. Beside oral narration, the development of other abilities is also vitally important for young children, e.g. space and object cognitive abilities. If powerful user friendly interaction methods, which are more intuitive and natural, are provided by digital storytelling systems, then the additional abilities (cognition and motor coordination) will also be considered.

There is a plethora of research in the psychology field which is used for development of important skills in children [9-12]. Research suggests that spatial-temporal reasoning and spatial visualization ability is an important indicator of achievement in science, technology, engineering and mathematics [13] and a pre-schooler's visual spatial attention ability predicts his future reading skills [14]. Researchers have also postulated a set of so-called "core domains" in cognitive development and suggested that children have innate sensitivity to specific kinds of patterns of information. Those commonly speculated core skills of cognition include: number [15], space [16], visual perception [17], essentialism [18], and language acquisition [19]. As an important aspect of children's psychosocial development, the significance of motor coordination competence has also been recognized in pedagogy long time ago. Children with poor motor coordination have been found to underachieve educationally and to experience difficulties with peer relationships [20].

Puppet Narrator is developed to target children between 5 and 8 years old. Our aim is to endow digital storytelling with a novel interaction method, which is more flexible and immersive. At the same time, our system is highly educational not only in terms of narrative competence but also cognitive ability and motor coordination. In our system, besides narrative ability training, we also pay attention to parts of these core skills developments: number, space and visual perception with the assistance of motion sensing technology in virtual environment. To enhance the children's motor coordination competence, by using depth motion sensor to track and recognize players' hand movement and gestures, our system enables children to use their hand motions to manipulate virtual puppet for interacting during narrating.

Our preliminary conception is: following the provided story plot, children will finish the whole story narration, and at the same time, children can simply use hand motion to control the movement of virtual puppet and interact with playthings in virtual scenario to assist narrating. Through this procedure, their narrative ability will be nourished. Using hand gestures for controlling the avatar, their motor coordination ability will be trained. In interaction with virtual items having different properties and roles in the story, their space and object recognition capability will also be developed.

Based on the above considerations, there are several aspects we should consider in our system design, as summarized below:

1. For the purpose of narrative ability training:
    a. Story topic should be carefully chosen, which should be familiar to the children and can be repeated and narrated easily.
    b. The story should have pedagogical meaning.
    c. The story plot should be provided to the children to follow before the story commences.
2. For the purpose of cognitive core skills' development:
    a. Numerical cognitive: players should finish a certain number of goals, denoted by a score within the game.
    b. Spatial cognitive: players should have a clear recognition of their hand's location in real world as well as the location of avatar and other playable objects in virtual environment. They will develop the ability to map the position of their hands from the real world to the position of the avatar in the virtual world.

c. Visual perception: players should have the ability to distinguish different playable objects having different functions and uses.

3. For the purpose of motor coordination ability training:
   a. Players are required to perform hand gestures correctly and in sequence.
   b. Players are required to move their hands steadily and accurately.

The structure of our training target is illustrated in Figure 2.

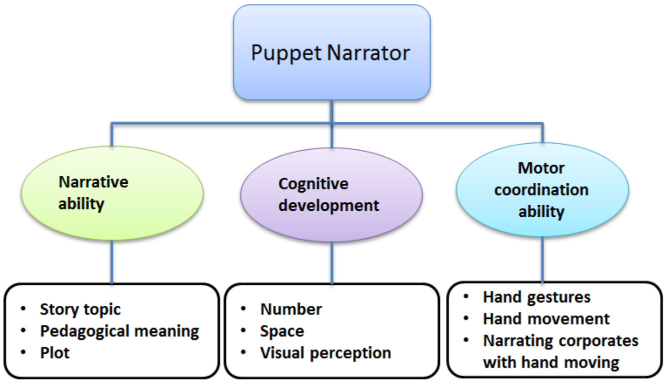


Fig. 2. Training target of Puppet Narrator

B. *Story Topic*

"The Crow and the Pitcher" is one most famous of Aesop's Fables. A thirsty crow found a pitcher with some water at the bottom out of the reach of its beak. The crow picks up pebble stones and drops them into the pitcher to raise the water level until it can drink the water. The fable is made by ancient Greek poet Bianor [21] and then collected by Avianus [22]. The fable emphasizes the virtue of thoughtfulness than brute strength and the value of the crow's persistence. Considering its popularity among young children as well as its positive pedagogical meaning, we choose "The Crow and the Pitcher" as the story topic.

During narration within our virtual environment young children could use their hands and a set of hand gestures to manipulate the puppet crow to pick up pebbles and drop them into the pitcher. The crow's actions, such as flying, grasping, and drinking will be presented through pre-recorded animations and controlled by hand gestures.

C. *Pipeline*

The component level interaction within the system is shown in Figure 3. First, a story plot is provided as storytelling hints to young players. Second, players use hand motion to manipulate the avatar through depth motion sensor device, which can automatically track hand motion and recognize hand gestures. Depth image data from the motion sensor are obtained and interpreted into motion control commands by the host computer. Finally, as the visual feedback, avatar's responding animation is provided to players and then, players adjust their hand gestures/movement to push the plot forward and narrate the story. Under this novel manifestation pattern, not only players' oral narrative ability but also their cognitive and motor coordination competence is expected to be developed.

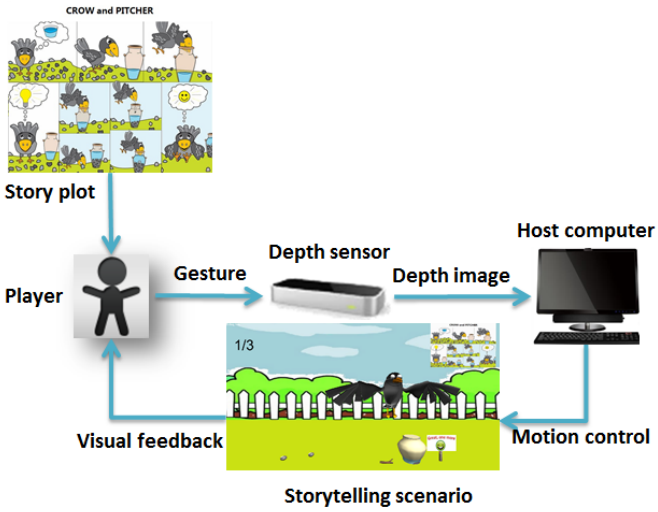


Fig. 3. System pipeline

III. IMPLEMENTATION

Puppet Narrator is mainly composed of three parts: Input, Motion Control, and Output, as illustrated in Figure 4. The input part processes the sensor data captured from motion sensor device through HCI and passes it to the next part. Motion Control interprets the data subsequently and determines avatar's location and posture. The output module updates avatar performance in virtual environment as the feedback.

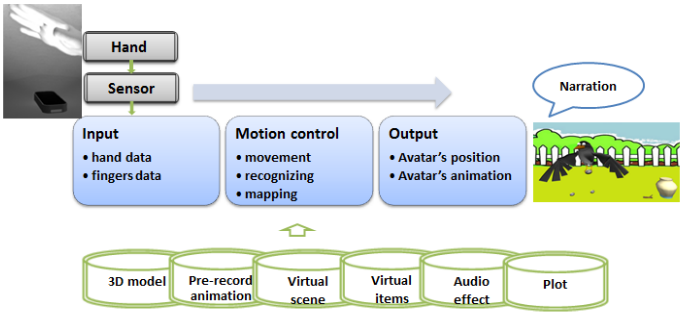


Fig. 4. System architecture

We utilized a Leap Motion controller in our system as the HCI sensor device to track hand gestures, which can provide a high fidelity finger tracking through an infrared depth sensor. We utilize the Leap Motion SDK provided by the Leap Motion Co. as the API to access the motion data of hands and fingers from the device. All the 3D models and animations were created in Maya 2014. We integrated and developed the entire system in Unity3D Pro V4.2.

A. *Digital puppet crow design*

To make our system more appealing for young children, considering puppetry's positive benefits in education, we use a digital puppet as an avatar to assist children's storytelling through animation technology.

1) Puppet geometry construction, which describes puppet shape, the rigging system, and its shading materials. The shape of the digital crow is modelled in Maya 2014 simulating the picture of the crow in the plot. Rigging the puppet defines its

behaviour with bones connecting joints. The sketched crow and the digital 3D crow model are shown in Figure 1(a).

2) User interaction, which defines the way players interact with the puppet, describing the performer expressions, and interaction interfaces.

3) Animation. Puppet crow uses pre-recorded animations to produce actions, which can be trigger by the players' hand gestures. Some screenshots are shown in Figure 5.

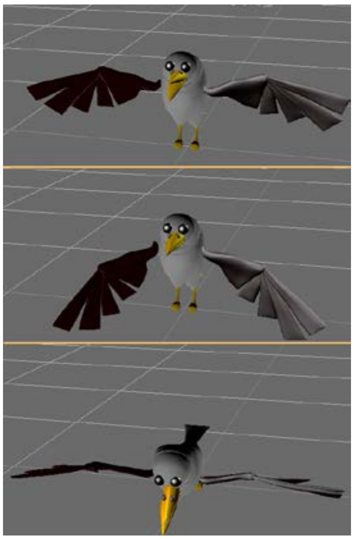


Fig. 5. Pre-recorded animations

B. Input data processing

The sensor data provided by Leap Motion controller contains a diversity of information about hands and pointables (such as fingers or finger-like tools defined by Leap Motion Co. [23]), in the virtual scene, which is updated by frame and can be represented as follows:

$$SensorData = \langle FR, H, P, T \rangle \quad (1)$$

where FR is frame rate; H represents the set of hands detected and P represents the set of pointables; and T is timestamp. Hand data H mainly contains the hand id, direction and different value about the palm position and status:

$$H = \langle id, dir, palmInf \rangle \quad (2)$$

And, pointables data P includes its id, direction and position information relative to the hand:

$$\mathrm{P} = \langle id, dir, handid, positionInf \rangle \quad (3)$$

C. Motion control

Recent research on neuroscience found that in human brain development there is a strong connection between perception, imagination and movement. According to previous studies [24-26], through the feedback of their own movement visual observation or the feedback of avatar's (3D virtual character's) motion [27], human can recognize and coordinate with their movements better.

The motion control module is the core of the system, which has two main functions: movement control and recognizing. Movement control function is responsible for mapping the play's relative hand position to the movement of the puppet crow. Recognizing function is in charge of identifying the pattern of hand movement and gestures implicating player's intention. Once a recognizable gesture is detected, recognizing function will trigger a pre-recorded animation or event (e.g. gripping a pebble or flapping wings).

1) Movement control mechanism

Since in a storytelling system children mainly focus on narrating, a complex puppet manipulation [28] as if we are stringing a puppet in a real show will be distracting or even hamper narrative. If young children pay much attention on puppet manipulation, they might forget the story line. From this consideration, we design a user-friendly puppet prototype used as a storytelling avatar with a simpler interaction manner and easier motion control mechanism.

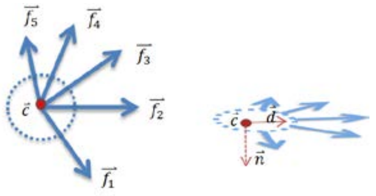
For young children to control the movement of the puppet/avatar, the most direct way is converting the translation of their hands position in Leap Motion coordinate system to the position of puppet in virtual environment. Considering the different scale between these two workspaces, a proper transformation matrix should be involved as a scaling into the coordinate translation. Once players' hands is not recognized by the Leap Motion device, puppet will keep its position in the last frame and then resume the movement immediately when hands can be detected again in the following frames. Within each frame, the position of the puppet is decided by the values of two coordinate vectors: the puppet's former coordinate in previous frame and the hand's relative translation generated by player's hand movement in current frame. And the scaling factor considered at the meanwhile, the puppet crow's coordinate in virtual workspace is computed as follows:

$$P_{crow} = M \cdot S \cdot R_{hand} + P'_{crow} \quad (4)$$

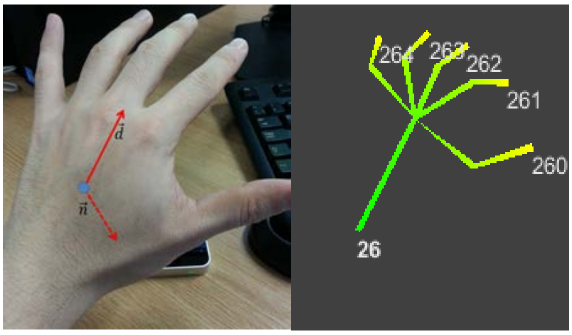
where P_{crow} is the puppet crow's position in current frame, R_{hand} is player's relative hand movement in real world in current frame comparing with the previous frame, which can be obtained in formula (2), M is the transformation matrix between the player's workspace and the puppet crow's coordinate system, S is the scaling matrix, and P'_{crow} presents puppet crow's position in the previous frame.

Hand model is shown in the right of Figure 6(a), where $\overrightarrow{f_i}$ ($i \in [1,5]$) presents the position of the finger tips (i is the number of recognized fingers), and $\vec{c}$ presents the centre of the palm. The plane of the hand is formed with the normal vector $\vec{n}$, and the directional vector $\vec{d}$. Vector $\vec{n}$ and $\vec{d}$ presents the normal and the directional vector of the hand plane. The player's hand and its virtual skeleton mapped are shown in Figure 6 (b).

For ease of controlling by young children, we define four intuitive motion controls: right, left, move downward and upward, which are mapped to different hand gestures, as shown in the upper two rows in Figure 1(b).



(a)



(b)

Fig. 6. (a) Hand skeleton model; (b) Player’s hand and its virtual representation

2) Hand gesture recognizing

For young children, in game environment, using hand gestures as in input to control avatar to perform is more natural and intuitive than other HCI method, such as using keyboard and touching screen. Unlike a screen-based system, a hand gesture input is clearly visible to others and constitutes an expressive action in itself.

When designing the system, a most important consideration is choosing a most natural and intuitive gestural interaction manner to play with the avatar. Considering their simplicity and demonstrated effectiveness, we utilize detectable pointing gestures [23] into HCI to reduce the operation difficulty of young children. To reduce the degree of difficulty of young children’s operation, some simple gestures are recognizable in our system, such as grip and stretch, as shown in the bottom row of Figure 1(b). Once a recognizable gesture is detected, recognizing function will call a pre-recorded animation of puppet crow linked with this gesture. And then, puppet crow will act as a real puppet and perform a pre-set action responding to player’s hand gesture in the virtual environment. The scenario of player’s using finger gestures to control the avatar is shown in Figure 1(c).

For the purpose of motor coordination training, players are required to perform hand gestures correctly, move hand smoothly and locate accurately, which contains two different aspects: hand movement and hand gestures. In our system, the data model of hand motion can be represented as follows:

$$Mot = \langle Mov, Ges \rangle \tag{5}$$

Hand movement includes move up (m_1), move down (m_2), move right (m_3) and move left(m_4).

$$Mov = \langle m_1, m_2, m_3, m_4 \rangle \tag{6}$$

And hand gestures include stretch (g_1) and grip (g_2).

$$Ges = \langle g_1, g_2 \rangle \tag{7}$$

Let J be the set of joints of the players’ hand being tracked.

$$J = \langle j_1, j_2, j_3, \dots j_n \rangle \tag{8}$$

Each joint j_i has a number of motions associated with it which can be represented by M.

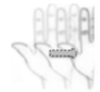
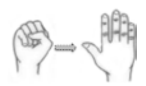
Then, each gesture g_i can be expressed as follows:

$$g_i = \langle j_i, m \rangle \tag{9}$$

where $j_i \in J$ is a joint, $m \in M$ is a motion associated to j_i.

With the definition of hand motion data model, we have designed a set of hand gestures which provide a natural and intuitive way for young children to interact with the playthings. Table I shows the mapping between hand gestures performed by players and the puppetry crow’s action in virtual environment.

TABLE I. HAND GESTURES MAPPING

Hand gestures	Motion	Crow action
	Move right	Fly to the right
	Move left	Fly to the left
	Move down	Fly down
	Move up	Fly up
	Stretch	Hover
	Stretch to grip	Grasp pebble/ stick
	Grip to stretch	Drop pebbles/ stick

D. *Output*

Output module updates puppet crow’s position calculated in motion control module and plays pre-recorded animations which have been linked with recognizable gestures in motion control. This module provides corresponding response to players as the feedback to adjustment of hand movement, which is vital for our cognitive development purpose as well as motor coordination ability training.

IV. RESULTS

The plot of “The Crow and the Pitcher” is presented first as the hint of the story, as illustrated in Figure 7. A scenario of Puppet Narrator during playing is shown in Figure 8.

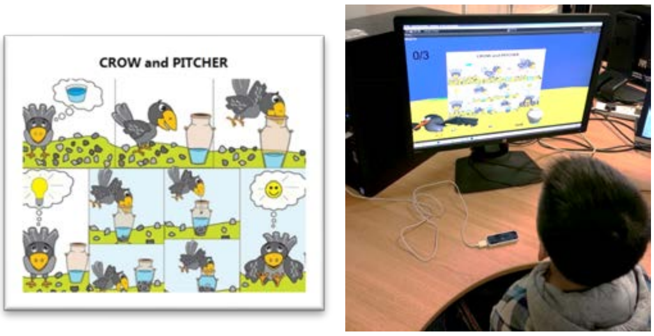


Fig. 7. Story plot*

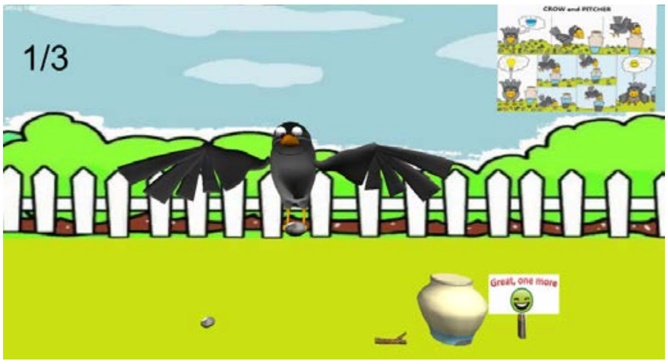


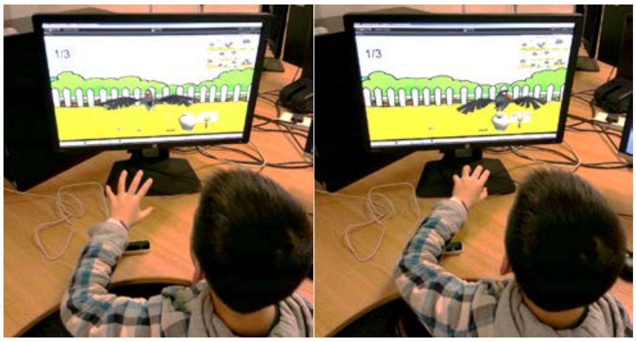
Fig. 8. A scenario of Puppet Narrator

In the scenario, there are five kinds of virtual items, each of which has different function, as shown in Table II.

TABLE II. VIRTUAL ITEMS

Icons	Name	Function
	Pebble	Fill pitcher for water rising
	Stick	Confuse player which needs to be differentiated from pebbles
	Pitcher	Collect pebbles dropped by crow and feed crow water after three successful drops
	Signboard	Provide information to player
1/3	Counter	Calculate how many pebbles are in dropped in pitcher

In Puppet Narrator, young children can use their fingers to control the animation of the puppet. In Figure 9(a), we can see that the player stretches his hand and move it to control the movement of the puppet crow by mapping the palm position to the crow's position. In Figure 9(b), we can see that the crow has grasped a pebble successfully and is preparing to drop it into the pitcher.



(a) Stretch (b) Grip

Fig. 9. Finger gesture

The storytelling procedure finished by a 7 year-old boy is recorded in Figure 10.

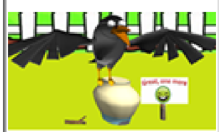
Plot	Virtual scene	Narrative record
		A crow is flying around on a hot summer day looking for water…
		He comes across a pitcher. Oops! He can't reach the water.
		He has an idea: collect pebbles and drop in the vase
		The crow drops pebbles in the pitcher. Water level rises.
		He takes lots pebbles and drops them into the Pitcher… He can drink water now!!

Fig. 10. Storytelling performed by a 7 year-old child

V. DISCUSSION

Four 5-8 years old young children are invited to participate in our preliminary test. With the instruction of provided story plot, all of the children could finish the story narrative and perform with great interest. During playing, some minor frustrations (or difficulties) are observed, such as picking up the stick by mistake, having problem to move the avatar toward the pitcher, or using a second hand to support the main hand in operation etc. Getting around these difficulties also made the children feel rewarded and find the game interesting.

* Fables of the world (https://www.pinterest.com/samargardezi/fables-of-the-world) accessed on 20 Mar, 2015.

After twenty rounds of experiment (five for each child), we have noticed that:

All the children could finish the game with few faults after a couple rounds of repeating.

All the children could narrate the plot with more complex words through their own language and understanding in the final three rounds.

For evaluation purposes, we set up some metrics from different aspects of our training procedure, and the result of each round of trial is recorded. The trend plot of average values of metrics is presented in Figure 11 and the details are shown in table III.

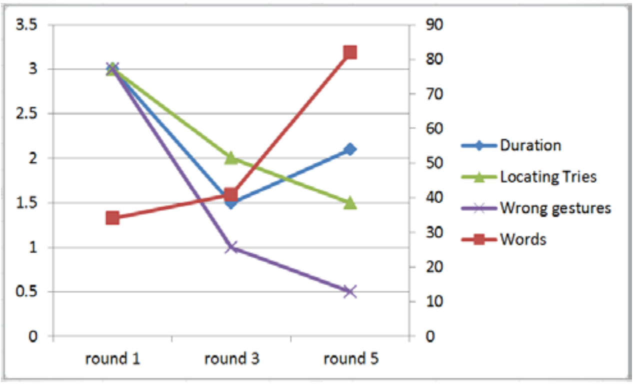


Fig. 11. Average values of metrics in experiment

TABLE III. EXPERIMENT RESULT

Metrics	Round 1	Round 3	Round 5
Duration of round (*M1*)	3 minutes	1.5 minutes	2.1 minutes
Narrative complexity (*M2*)	32 words	41 words	82 words
Number of tries to locate pebble (*M3*)	3 tries	2 tries	1.5 tries
Number of tries to pick up stick (*M4*)	1 try	0 tries	0 tries
Hand movement (*M5*)	disorder	smooth	smooth and rapid
Wrong hand gestures (*M6*)	3	1	0.5

Both Figure 11 and table III shows the quality of improvement of young participants' performance over several rounds of trials. Ability to successfully locate the pebble (*M3*) is improved by practicing picking up or dropping pebbles which can be indicated by the decline of locating tries (shown by green line in Figure 11). The average number of tries of picking up the stick by mistake (*M4*) drops from 1 to 0, which means that children can distinguish the stick from pebbles after 2 rounds of training. Hand movement (*M5*) and wrong hand gestures (*M6*) in the later stages of the experiment are improved over the earlier attempts.

We noticed from the experiment that young children were able to tell the story confidently and use more words and longer sentences in the last two rounds of trials, with some encouragement. One typical example is the sentence created by a 7 year-old boy at the start of the story: in the first trial, the boy used the sentence "A crow is looking for some water." In the third trial, he rephrased the sentence to "A thirsty crow is flying around looking for water." After adding more decorative words, the sentence finally transformed to "A thirsty crow is flying around on a hot summer day looking for water." It is obvious that the narrative ability was enhanced during storytelling, which is reflected by metric *M2* (red line in Figure 11). One interesting thing we found is change of duration of narrating the story (*M1*). Initially, participants used 3 minutes on average to complete the whole narration and then they could finish it within 1.5 minutes, which benefits from getting more familiar with the system. Finally, the duration of narration tends to last a litter longer. The reason is that once young children get used to the control mechanism and the interaction interface, they tend to pay more attention on the story line and the improvisation, which is vital for storytelling and more suitable for pedagogical purpose as a learning tool for children.

During the test, the aspects of children's cognitive competence and motor coordination ability were trained with obvious improvements.

Numerical cognition: all the three pebbles need to be dropped into the pitcher before the crow can drink water, which requires the players should have a basic numerical cognition to finish the mission.

Spatial cognition: pebbles could only be picked up within predefined area and dropped into the pitcher, which means the spatial cognition ability is required in locating the pebble.

Visual perception: there are several kinds of virtual items in the scenario and each of them has different property and usage, which means the players need to distinguish them from others and make correct choices, for example, only pebbles can make water to mount up and the stick will not work.

Motor coordination: only predefined hand gestures could be recognized by our system, which means players need to perform hand gestures correctly. For controlling the puppet crow, players need to use hand motions as the input to manipulate the crow in virtual environment and adjust hand gestures according to a visual feedback received from the crow's responding movement. This requires players to move their hands smoothly and steadily, which reflects a better motor coordination of limbs. During the performance, players' narration often incorporates with hands movement and changing gestures, which also requires perfect coordination.

We plan to exploit our system to conduct indicative experiments with more subjects to identify the pros and cons with quantitative data and analysis. We will also include other story templates in the game. This will introduce new gestures and pose additional operational complexity for young children.

VI. Conclusion

We have presented a novel digital storytelling system assisted with virtual puppetry, Puppet Narrator, providing young children with natural interaction/control and immersive experience when narrating story. The system is designed to support training of different cognitive skills and motor coordination through storytelling. It has been a novel attempt to include advanced motion sensing technology and computer animation as a medium for this development.

Besides its positive pedagogical significance as a digital storytelling system, our system also helps develop young children's skills and knowledge related to ICT.

The usability of the system is preliminary examined in our test and the results from the analysis are promising, which showed that young children can be benefited from their playing with Puppet Narrator. However, as only a limited number of subjects are tested, we will need to examine more cases and design a psychological experiment to affirm the conclusion. Further validation and analysis of the effectiveness of this approach is needed, but at the moment our observation and analysis can be supported with success of other parallel development in digital story telling [8].

The story telling in our test is a supervised learning process where an adult will provide guidance and helps, which is important for the young ones can accomplish their narrative task and receive proper trainings. Without the presence of supervision, it is possible that the virtual puppet may distract the story telling that the child would focus on the playing and controlling of the puppetry without practicing their narration. It will request a rewarding strategy in the future development of such system to automatically encourage and reward the players when they accomplish the narrative task properly.

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