PuppetX: A Framework for Gestural Interactions with User Constructed Playthings

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ABSTRACT

We present PuppetX, a framework for both constructing playthings and playing with them using spatial body and hand gestures. This framework allows users to construct various playthings similar to puppets with modular components representing basic geometric shapes. It is topologically-aware, i.e. depending on its configuration; PuppetX automatically determines its own topological construct. Once the plaything is made the users can interact with them naturally via body and hand gestures as detected by depth-sensing cameras. This gives users the freedom to create playthings using our components and the ability to control them using full body interactions. Our framework creates affordances for a new variety of gestural interactions with physically constructed objects. As its by-product, a virtual 3D model is created, which can be animated as a proxy to the physical construct. Our algorithms can recognize hand and body gestures in various configurations of the playthings. Through our work, we push the boundaries of interaction with user-constructed objects using large gestures involving the whole body or fine gestures involving the fingers. We discuss the results of a study to understand how users interact with the playthings and conclude with a demonstration of the abilities of gestural interactions with PuppetX by exploring a variety of interaction scenarios.

Categories and Subject Descriptors

H.5.2. [**Information Interfaces and Presentation**]: User Interfaces, Input devices and strategies

General Terms

Play, tangible interface

Keywords

Full body gestural interactions, modular framework, digital and physical puppetry

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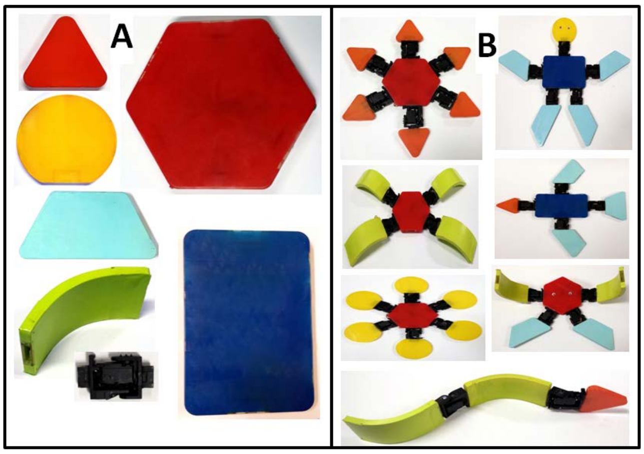

Figure 1: PuppetX Framework A) Components developed B) Puppets created using these components.

1. INTRODUCTION

The past two decades have seen the introduction of a number of physical products with embedded electronics, ranging from modular robotics [13, 25]; construction kits such as Lego Mindstorms, Easigami, Posey, Topobo and Robo-Topobo [8, 15, 16, 17, 21]; puppetry such as CoPuppets [1], Shadowstory [11], and Shape Your Body [10] . In these physical embodiments, objects reveal themselves as emotional and intellectual companions that anchor and sustain relationships, allowing one to connect to the objects in new ways. Although users can construct some of these toys and objects on their own, they are limited by not being able to interact with them naturally like we do with each other through gestures. In other studies, user constructed objects have been shown to promote self-extension into them and to be more engaging [3]. Gestures including motions of our hand and body are some of the most direct ways in which we communicate our thoughts and feelings. Even at a subconscious level we continuously interact with our physical world via body gestures. We believe that it is very intuitive to control objects via gestures.

However the user constructed objects do not lend themselves to easy control or programming during interaction. To overcome the inherent limitations of designed and constructed objects in their ability to interact naturally with humans we present and explore PuppetX. Using gestures as an input makes it possible to use hands for tailoring the interactions to be intuitive by using prior human experience of real-worlds manipulations. We can imagine a gesture to be a symbolic representation of some real world action; so, it can be thought of as a tool to leverage prior human knowledge. Using a depth sensing camera makes it possible to do all the above without additional hardware on the hand.

User constructing the devices and subsequent spatial interaction and the programming of these devices with gestures has not been explored in prior research. In this paper we explore the intersections of two important trends.
(1) Using modular construction components as tangible interface to create playthings, and
(2) The 3D gesture control as a user interface to interact with and program the user constructed objects.
Our overall motivation is to democratize the programming of user created playthings and make it easier for various age groups to construct and program the gestural motion inputs. PuppetX is a set of passive and active components that can be joined together in various configurations to make different topological constructions. We call them playthings since the user can immediately interact or play with them after constructing them. The modular nature of the hardware design creates affordances that allow users to make a variety of playthings. PuppetX provides a new type of play value. In this paper, we demonstrate creating and using the interactions with playthings which are very similar to puppets. We conducted a user study to understand the different gestures a person may use to interact with these playthings. Based on the results of the study we developed the software to control the plaything in the most natural way using body gestures. In our system, when a user joins the components to create tangible playthings, its topological information is relayed to the computer. Based on this information a virtual model of the plaything is also developed which can be animated by the users. The animate-able playthings are in two forms. The first type resembles anthropomorphic characters such as Bird, Crab, Huggy, Robot and Snake, and the second kind resembles non-anthropomorphic characters like Flower and Starfish. We present the following scenarios to show the features of PuppetX.
Scenario 1 - Playing with anthropomorphic playthings via body gestures.
Scenario 2 - Playing with non-anthropomorphic playthings via finger gestures.
Scenario 3 - Interacting with playthings where the gestures are targeted through an off-line mode of programming.

1.1 Contributions

Our aim for developing PuppetX is to democratize gestural programming of user-constructed objects, and in that process we also make a contribution to a variety of fields:
• Our design framework consists of a modular hardware and software platform to create playthings and everyday objects that are topologically aware. The mapping between hardware and software platform enables a real time gesture controlled pipeline that tracks users or responds to their gestures.
• We create a virtual proxy of the physical plaything enabling an off-line programming mode.
• We define and develop full body and finger gestures combining them together as a control mechanism for interacting with the playthings.
Upon construction the playthings become topology-aware and gesture controllable. We demonstrate compelling scenarios, from a new form of theatre for play and puppetry, showing the use of advanced gestural programming of user constructed playthings.

2. RELATED WORK

PuppetX draws its inspiration from a multitude of fields, namely tangible interfaces, reconfigurable robotics, puppetry, gestural interaction and interfaces, animation, and psychological aspects of gestures and emotions. We describe them in order below and finally examine some current trends.

2.1 Tangible Interfaces

The role of physical objects in the development of young children has been studied extensively in the past. Researchers have developed mechanisms which allow users to connect tangible/ physical objects to create an assembly, the 3D representation of which is created in a computer [8, 21]. These allow users to build and move the parts of an assembled model via a ball and socket mechanism [21] or via hinges and polygonal shapes [8] which creates a CAD model with the topological information. Construction kits which allow users to create toys and program them using computers [17] or using physical motion [16] are very engaging and have been shown to accelerate an understanding of motion and system dynamics. Similar to tangible interfaces a variety of modular robots have been developed which are autonomous and are self reconfigurable [13, 25]. Programming by example in this context makes the educational ideas implicit in the design of toys accessible to young children [2]. To democratize programming using tangible interfaces, McNerney developed a programmable and configurable physical blocks [12] which controlled virtual objects. Tern [6] was another tangible programming system which uses computer vision to recognize and compile programs represented using physical blocks, and aids students in learning programming. Our system is different from these since we tried to directly incorporate natural gestures of the users into the programming process.

2.2 Puppetry

Interactive storytelling has long been synonymous with puppetry. Researchers have explored the possibilities offered by multi-modal and cooperative interaction with virtual puppets in constructing a communicative experience through gesture and voice [1]. Studies with storytelling system with user created and controlled digital characters have illustrated that they promote creativity, collaboration and intimacy among children [11]. Additionally by using our whole body as a controller of virtual silhouette, researchers have shown that the performance is just as expressive and intuitive as that of a traditional puppet [10]. A separate variety puppetry has been developed, which uses camera for detecting motion in physical objects to produce 3D animation [5] . Our work is similar to this in its sensing mechanism to produce animation but differs fundamentally in the way in which the puppets are created and animated. While the puppeteers need to have pre-made puppets for interface in 3D Puppetry [5]; our interface encourages the puppeteer to explore their imagination for creating their own puppets and animating them. On a different note, puppets have been shown to help increase interaction with children and to promote engagement and discussion about science [20].

2.3 Gestural Interaction

To define the appropriate and relevant terminology for the conceptual and technical descriptions of hand-based interaction systems, we adapt the definitions provided in [7] and extend them to the arms. The process of hand-based interactions is divided into hand and arm pose, hand and arm motion, and hand and arm gesture. Poses are defined as the individual spatial configurations of the wrist, palm and fingers (hand) and elbow and shoulders (arm), which are devoid of motion. Motion is the temporal variation of the spatial configurations of the hand and the arm, i.e. it deals with the dynamic articulations of the hand and arm by obeying some kinematic constraints. Gesture is defined as a combination of pose and dynamic hand and arm movements to convey a certain meaningful action.

2.4 Animation of 3D Models

Work related to animating the virtual 3D model of the plaything lies in animation research, where human body movement is tracked and retargeted to animated figures. Systems have been developed which allow animating characters whose morphologies are unknown at the time the animation is created [4]. This system called, Real-time Motion Retargeting to Highly Varied User-Created Morphologies [4] is similar to our concept where the animation of the 3D model is defined based on the topological construct of the plaything that the user has created. Human motion capture data has been used to generate animation for non-humanoid characters which have topology significantly different from humans.

2.5 Psychological or Cognitive Aspects

When the users interact with our system via hand and body gesture they unknowingly exhibit some emotions. Gestures and emotions are highly correlated [9]. Research has shown that when body motion is augmented with adjectival expression it leads us to perceive those motions as being related to certain emotions [24]. For example large gestures are correlated with joy and slow gestures with fear. We argue that our system is capable of exhibiting such emotions by combining motions with adjectival expressions. Additionally, research shows that the process of creation enables extension of one's sense of self into objects that one creates [3]. People showed greater self extension into their creation and preferred its personality over others. For these reasons, we believe that by creating their own playthings our users will be able to engage themselves more while playing with it.

2.6 Current Trends

The current trend is to make socially assistive robots and developing ways to apply robots as therapy tools. Robots used for autism research have shown to improve engagement and elicit novel social behaviours from people (particularly children and teenagers) with autism [19]. Increasingly robots are becoming capable of moving and acting in human centered environments interacting with people. There is a need for robots to use their bodies to communicate and react to users in a socially engaging way. Apart from that gesture identification has become ubiquitous in nature with the

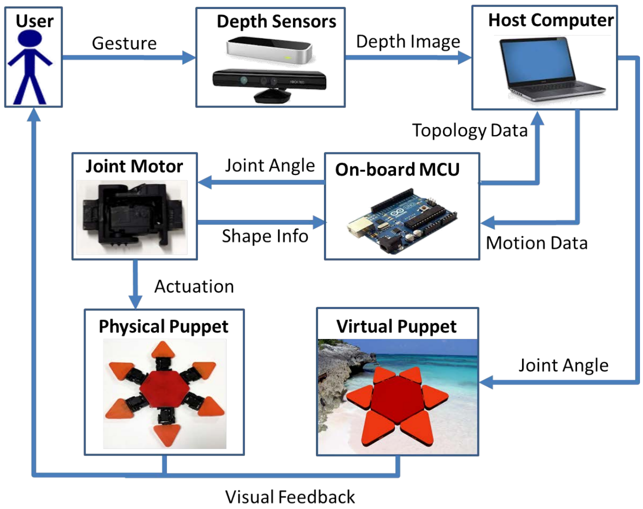

Figure 2: System Pipeline.

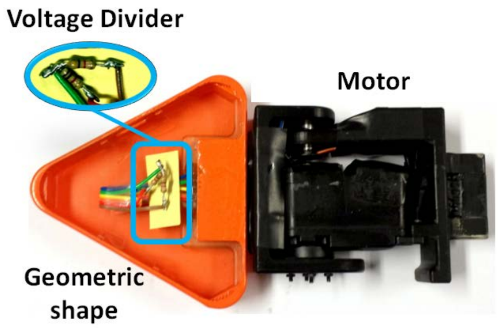

Figure 3: Self identification mechanism connected to the Joint.

widespread use of MicroSoft Kinect ®and Leapmotion®[1] sensors. Our overall direction is towards democratizing the programming of user constructed objects using hand and body gestures.

3. HARDWARE DESIGN

In this section we describe the details of a proof-of-concept prototype which enables us to create a self-identifying, modular design. The pipeline showing component level interaction within the system is shown in Figure 2.

3.1 Modularity

The design constraint we had for making the parts of the playthings was to give them the ability to be reconfigured into various topological constructs. For this purpose we made a common connector and links of various shapes. The common connector, called as Joints hereafter, has a motor and two male protrusions which allow it to be connected to the shapes. Electrical connections are embedded into the protrusions of the joints such that when the components of playthings are connected they complete the circuit (Figure 3). These joints also have a Atmel microcontroller placed into them which helps in the self-identification mechanism

[1]https://www.leapmotion.com/

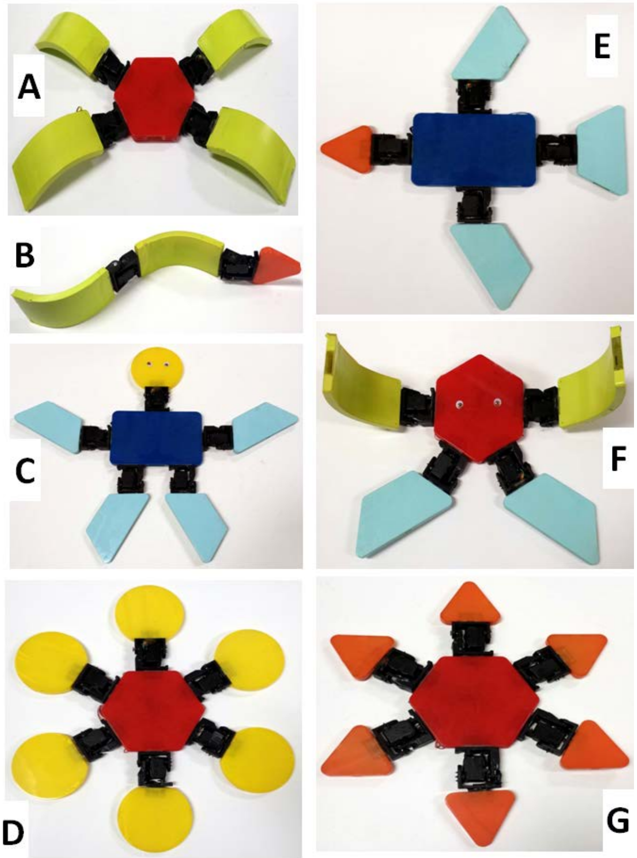

Figure 4: Some representations of anthropomorphic puppets like: A) Crab B) Snake C) Humanoid E) Bird F) Huggy and non anthropomorphic puppets like D) Flower G) Starfish.

explain below. The design of the links is inspired by basic geometric shapes. The links we have designed are shaped as rectangle, hexagon, triangle, circle, trapezium and a curved shape shown in Figure 1. These links have a female connector shaped such that it allows the male protrusions of the joints to be connected to it. The links have a voltage divider circuit built into them. Each shape is associated with a voltage divider circuit which gives a unique voltage that acts as its identifier in the self-identification mechanism explained below. Magnets with opposite polarity are placed in each of male / female protrusions which allow a strong connection once they are put together.

3.2 Self identification

Once the play things are constructed using the links and the joints they must send the details of their topological construct to the main micro-controller which sends this data to the PC which in turn builds up its "topological model". Based in this topological model the PC allows the user to play with the playthings. Each of the links is identified based on a combination of resistances which make a voltage divider circuit (Figure 3). The Atmel micro-controller detects the voltage available due to the voltage divider circuits and based on this voltage it identifies which shape it is. This shape information is stored in the main micro-controller as a unique flag which represents the shape. It sends the Atmel micro-controller ID and the shape information data to the PC forming the topological model.

3.3 Electronics

The physical playthings is interfaced with PC via serial communication and I2C communication protocol. During the first few seconds of putting together the play-thing it is in the self-identification mode where I2C communication takes place once that is over serial communication protocol is put in place. This switching happens via an NPN transistor. The main microcontroller, Arduino Mega, collects all the information via I2C protocol from the individual Atmel microcontrollers in each joints and sends them to the PC via serial communication. At the later stage of animation the angle data is sent to individual motors via serial communication protocol.

3.4 Playthings Possible

As per our design a plaything has to be made in a way that all other parts are attached to one central hub. The central hub contains the main micro-controller which obtains data about the shapes attached to it from the micro-controllers in the links and uses it to develop the topological model. This necessity of having a central hub for making the playthings acts as a limiting factor in our design. Even then, we can join many of these pieces together to make more than 5000 different topological constructs. In this paper we explore the usage scenario of seven of these constructs, which represent familiar objects such as Bird, Crab, Snake, Humanoid, Starfish and Flower, and an imaginary creature Huggy. Some of them are anthropomorphic while others are not as shown in Figure 4.

4. SOFTWARE DESIGN

In this section, we present the details of the algorithm to interpret the motion data obtained from the depth sensors used to identify the full-body and hand-and-finger movements.

4.1 Body and Finger Motion Tracking

In the implementation of our system, virtual 3D puppet models are designed using SolidWorks, and animated with the motion of user captured by depth sensing cameras: a Kinect and Leap Motion sensor. The skeletal data of user is given and tracked by using the Kinect camera and OpenNI library. In our current implementation, the exponential smoothing filter is used to reduce noises from the Kinect camera and stabilize each tracked joint position. The exponential filter is computationally simple but still gives enhanced stability of joint position tracking in our application. To track the motion of hands and fingers, we use the Leap Motion sensor which provides about 0.01 mm precision in tracking. Leap Motion SDK is incorporated in our software to obtain the pose of hands and fingers from the motion sensor. The real-time visualization of puppet is developed in Microsoft Visual Studio 2010 using OpenGL.

4.2 Interpretation of Motion Data

Full body motion: The tracked full body skeleton models and joint position is depicted in Figure 5. Each joint location $\overrightarrow{r_i}$, $i \in [0, 14]$, is measured from the inertial reference frame ($\mathcal{K}$: K_o, $\overrightarrow{K}_x$, $\overrightarrow{K}_y$, $\overrightarrow{K}_z$). The direction vectors

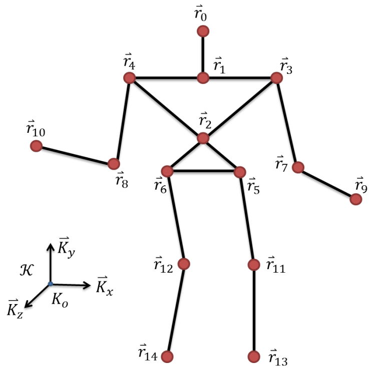

Figure 5: Skeleton of human body as built by the depth camera.

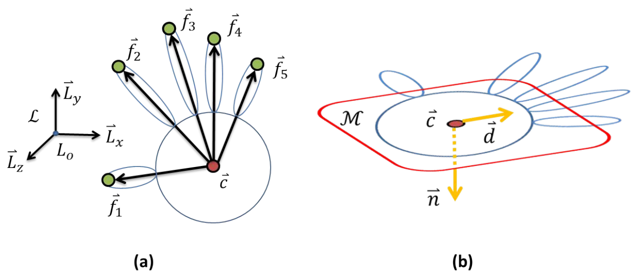

Figure 6: (a) Skeleton of hand (b) A plane formed with normal and pointing vector of hand.

of the joints are used to calculate the angles controlling the motion of physical and virtual puppets. For example, the angle between the direction of the right arm ($\overrightarrow{r}_{8/4} = \overrightarrow{r}_8$ - $\overrightarrow{r}_4$) and the vector joining points indicating the neck and the torso center ($\overrightarrow{r}_{2/1} = \overrightarrow{r}_2$ - $\overrightarrow{r}_1$) is referred to define the rotation of the right arm of Humanoid or the upper right leg of Crab, and is expressed as $\angle(\overrightarrow{r}_{8/4}, \overrightarrow{r}_{2/1})$ where the scalar function $\angle(\cdot)$ represents the angle between two vectors.

Hand and finger motion: The skeleton model of the tracked hand is shown in Figure 6 (a). The position of the finger tips, $\overrightarrow{f}_i$, $i \in [1,5]$, and the center of the palm, $\overrightarrow{c}$, are measured with respect to the inertial reference frame ($\mathcal{L}$: L_o, $\overrightarrow{L}_x$, $\overrightarrow{L}_y$, $\overrightarrow{L}_z$). A plane, $\mathcal{M}$, formed with the normal $\overrightarrow{n}$ and the directional vector of the hand $\overrightarrow{d}$ is shown in Figure 6 (b). The finger motions controlling non-anthropomorphic shape of puppets are identified using the angles between the finger pointing vectors $\overrightarrow{f}_i - \overrightarrow{c}$ and their projections onto the plane $\mathcal{M}$. These angles can be represented as $\angle(\overrightarrow{f}_i - \overrightarrow{c}, proj(\overrightarrow{f}_i - \overrightarrow{c}, \mathcal{M}))$ where the function $proj(x, y)$ stands for the projection of the vector x onto the plane y. The choice of joints and motions to control the motion of the puppets is based on the user study described in the following section. For identifying the play-thing that is constructed by the user we created a reference library which links each geometric shape with a flag.

4.3 Defining Set Of Gesture for Interaction

The challenge in designing the software for gestural interaction with user constructed object lies in identifying the most natural way in which a person would like to play with playthings. Since there are no precedents to such objects or interaction we designed a user study to understand how users would like to interact and play with the playthings made using the PuppetX framework. We wanted users who had well defined manipulative skills for our test and hence we decided to do the study on university students. Twenty-five participants from different disciplines of Purdue University volunteered for the study. Eleven were female. Average age was 23 years. The study was divided into two parts. The first part was designed to get unbiased feedback on the way in which a person would move their body to interact with the playthings. We explained the capabilities of the PuppetX framework in a non-technical way to the participants while avoiding any details of the method of motion sensing to prevent any biases. We asked the users to assume that they had full control over the playthings. The users were then asked to move their body and show us what body gesture would they use to control the playthings in the most comfortable way. We repeated the exercise with each of the seven playthings in a random order and video recorded their motion.

In the second part of our study, we explained to the users about our motion tracking capabilities and asked them to tell us what mapping between joints did they think was most natural way to control the playthings. They were given the choice of 9 body joints which include two elbows, two shoulders, neck, two hip joints and two knees and they made one on one mapping between their body joints and the joints in the playthings provided to them again in a random order.

4.4 Conclusions From User Study

From the first part of the study we observed that the users tend to use only simple body motions to interact with playthings. These motions can be categorized into the following: flapping the arms, swiping the arms, swinging the arms, moving the legs to and fro, moving the legs side to side, bending waist and nodding head. These sort of motions can be implemented by simply computing the angles between the direction of limbs and the reference vector $\overrightarrow{r}_{2/1}$ as described previously. An interesting trend that surfaced was the usage of fingers to control playthings which have far more parts than the limbs in our body. It turns out that users preferred to control non-anthropomorphic playthings like the Flower and Starfish, which have six joints each, by using fingers rather than body. As a result we develop a system which is independent of the sensor being used and which could respond to finer motor movements like fingers as well as to larger body movements alike. To measure and compare the agreement levels in the selection of the control joints during the second test, we compute an agreement score A which is used in guessability studies to measure the degree of consensus among symbolic inputs or user-defined gestures [14, 18, 22, 23].

$$A = \sum_{P_l} \left(\frac{|P_l|}{|P_r|} \right)^2, A \in [0, 1] \tag{1}$$

where P_r is the number of joint mappings to control a puppet and P_l is a subset of P_r which is configured with the same set of control joints. Eight users for Flower and five users for Starfish initially tried to use their hands or individual finger to control non-anthropomorphic puppets. Also to

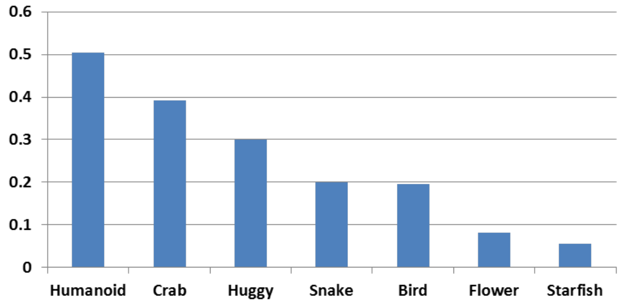

Figure 7: Agreement score for each puppet scenario in descending order.

Puppet Type	Joint Angle Mapping for Puppet Control
Humanoid	Head: $\angle(\vec{r}_{0/1}, \vec{K}_y)$, Left arm: $\angle(\vec{r}_{8/4}, \vec{r}_{2/1})$, Right arm: $\angle(\vec{r}_{7/3}, \vec{r}_{2/1})$, Left leg: $\angle(\vec{r}_{12/6}, \vec{r}_{2/1})$, Right leg: $\angle(\vec{r}_{11/5}, \vec{r}_{2/1})$
Crab	Upper-left leg: $\angle(\vec{r}_{8/4}, \vec{r}_{2/1})$, Upper-right leg: $\angle(\vec{r}_{7/3}, \vec{r}_{2/1})$, Lower-left leg: $\angle(\vec{r}_{12/6}, \vec{r}_{2/1})$, Lower-right leg: $\angle(\vec{r}_{11/5}, \vec{r}_{2/1})$
Huggy	Left arm: $\angle(\vec{r}_{8/4}, \vec{r}_{2/1})$, Right arm: $\angle(\vec{r}_{7/3}, \vec{r}_{2/1})$, Left leg: $\angle(\vec{r}_{12/6}, \vec{r}_{2/1})$, Right leg: $\angle(\vec{r}_{11/5}, \vec{r}_{2/1})$
Snake	Head: $\angle(\vec{r}_{0/1}, \vec{K}_y)$, Tail: $\angle(\vec{r}_{12/6}, \vec{r}_{2/1})$ or $\angle(\vec{r}_{11/5}, \vec{r}_{2/1})$
Bird	Head: $\angle(\vec{r}_{0/1}, \vec{K}_y)$, Left arm: $\angle(\vec{r}_{8/4}, \vec{r}_{2/1})$, Right arm: $\angle(\vec{r}_{7/3}, \vec{r}_{2/1})$, Tail : $\angle(\vec{r}_{14/12}, \vec{r}_{2/1})$ or $\angle(\vec{r}_{13/11}, \vec{r}_{2/1})$
Flower / Starfish	1^{st} pedal: $\angle[\vec{f}_1 - \vec{c}, proj(\vec{f}_1 - \vec{c}, \mathcal{M})]$, 2^{nd} pedal: $\angle[\vec{f}_2 - \vec{c}, proj(\vec{f}_2 - \vec{c}, \mathcal{M})]$, 3^{rd} and 4^{th} pedal: $\angle[\vec{f}_3 - \vec{c}, proj(\vec{f}_3 - \vec{c}, \mathcal{M})]$, 5^{th} pedal: $\angle[\vec{f}_4 - \vec{c}, proj(\vec{f}_4 - \vec{c}, \mathcal{M})]$, 6^{th} pedal: $\angle[\vec{f}_2 - \vec{c}, proj(\vec{f}_2 - \vec{c}, \mathcal{M})]$

Table 1: Joint angle mapping between the skeleton and humanoid puppet

control these two puppets, the users suggested nineteen and twenty different joint mappings for Flower and Starfish, respectively. However the users elicited less than eleven joint mappings to control other puppets: six for Crab, seven for Huggy, eleven for Snake, four for Humanoid, and seven for Bird. Based on this categorization we computed agreement

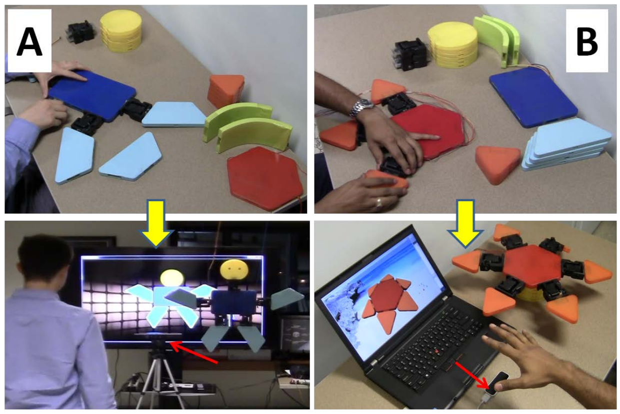

Figure 8: A) Scenario 1 - Play with body gestures. B) Scenario 2 - Play with finger gestures. Red arrow shows the depth sensors.

scores A for each plaything. As shown in Figure 7, the participants scored the highest agreement as 0.50 in the selection of joints to control Humanoid while Flower and Starfish showed only 0.082 and 0.056 agreement score.
Based on the user study results we completed the mappings between the joints of users and puppets as described in Table 1 and it also informed our interaction design. The joint location of the body and hand are represented in Figure 5 and 6. As we observed from the user study, the users did not agree in the control of Flower and Starfish using the full body motions. Depending on the observation that meaningful number of users suggested the use of hands and fingers instead of bodily movement, we extended our motion sensing capability to the level of finer finger movements.

5. INTERACTION SCENARIOS:

The PuppetX framework gives users a lot of freedom to create and play with their own creations. In this section we present three scenarios which showcase all the capabilities of our framework.

5.1 Scenario 1: Real time play using body gestures

In the first scenario (Figure 8 A), we describe the capabilities of PuppetX as a framework to construct playthings as desired by the user. When a user is presented with all the components of PuppetX, the user has a choice of connecting them in many different configurations. In this scenario the user makes a humanoid puppet using a rectangle, four trapezoids and a circle. Once the puppet has been made the computer determines its virtual model and based on it the user gets to play with their creation. After making their plaything the users decide to play with their puppets by interacting with them via body gestures detected by a depth sensing camera.

5.2 Scenario 2: Real time play using finger gestures

We came upon this scenario after observing the users' preference to control non-anthropomorphic puppets with fingers. In this scenario (Figure 8 B), we show that a user can put together the PuppetX components to make a non-anthropomorphic plaything. The user makes a starfish puppet using a hexagon and six triangles. They can then use their fingers to control the playthings. Each of their fingers is mapped to the joints of the plaything and by moving their fingers they control the plaything as if controlling them like marionettes.

5.3 Scenario 3: Gestural Programming and Off-line Playback

If two users are interacting with two different playthings separately, their body motion data is stored in the computer, so when both of them are done playing they can playback the same motion on the puppets and together these puppets can enact a story. We call this process gestural programming. This form of programming the puppet motion does not even require traditional programming expertise.

A similar scenario can also takes place in two different places. At one place, a person uses the PuppetX components to create a physical puppet. The associated virtual puppet is sent to another other user at a different place who programs it using gestures. Once gestural programming is done the stored motion data is replayed back to the initial user who can play it back in their physical puppet. This scenario shows the ability of our system to connect people over distance as well as its ability to play back stored motion capture data. It also demonstrates the advantages of having both the physical and virtual representations of the puppets.

6. DISCUSSIONS

In the past few decades, considerable effort has been spent on animation and virtual scenarios as well as development of games including massively multi-player games in the recent years. We feel that while that has advanced software systems, computer graphics and animations, we have not explored or created platforms where users can build physical things and animate or program them with natural user interactions with gestures. Understanding the new values of play that involve full body interaction and learning can facilitate creativity in designing these new systems. 21st century technologies enable learning and facilitate ubiquitous, highly interactive, and social connections during play that fundamentally change the shape of knowledge creation, sharing, and development. We discussed the functioning of our systems with experts in the field of puppetry and education. According to them the advantages our system has over traditional puppetry systems is that unskilled people can become puppeteers. Most traditional puppeteers make their puppets, write and direct their plays and then perform them. To use our system, being skill-full in fine arts or electronics is not a prerequisite and this decreases the barriers to enter the world of puppetry. We also learned from the experts in the field of education that the feature of having gestural programming followed by offline playback is useful for kids to act with these puppets and then observe and reflect their actions during the offline mode.

Our puppeteers' envisioned applications include educational tool for storytelling with kids, as a therapeutic tool for kids who have difficulty in interacting with others (like Autism) and entertainment puzzle/ toys. New forms of theatre can emerge from the ability for any common user to construct and program the playthings. New kinds of toys can be designed to take advantage of the affordances created by gestural programming to interact with these new forms of playthings as 3D depth sensing cameras becomes more ubiquitous, accessible, miniaturized and embeddable in toys. Our environment can also promote play in a social context and enable new forms of story telling. The actors can use gestures to program the PuppetX and the resulting act can be a play. New forms of theatre can be explored in the future. In developing PuppetX, and making use of the affordances of depth sensing to understand gestures of hands and body, we are able to engage the users full body or finer motions during the play. In doing so, we create and explore a new form of construction-play interface, which has potential for engaging the player(s) and the audience in many ways.

6.1 Limitations

Currently the software developed for gestural interactions are limited to the seven playthings that we have used to study the users' behaviour. Limitations also include the capacity of the motor to lift a maximum weight of parts. We have tried to address this limitation by providing an off-line proxy model that may be programmed apriori. Another limitation is the number of gestures that future systems can support and gesture design into the interaction. Mis-interpretation of a gesture is a concern. It can result in awkward motion and or physics not being followed or the animation not being smooth. In the current modality of control of puppets hanging from the top we are able to animate them via gestures. However they cannot move towards each other and also orient themselves with respect to each other. Although this information is available in the users' movement, we are not using it at the present time. The present design allows for rotation about only one axis in the joints. One axis gives only one movement and consequently can express only one emotion which might not be enough to express the wide range of emotions that users would like to exhibit.

7. FUTURE WORK AND CONCLUSIONS

PuppetX hardware and software platforms can be extended and improved upon in many new ways. Although work has been done in related areas, the affordances created by our work can spawn many new areas of related research. The software platform can be made modular and the capability to merge and edit multiple layers of action during the final play can be built in. Additionally, to enhance the customizability of our system, we are developing the software such that users can control the mappings themselves and use custom gestures.

Another exciting direction is to explore social and collaborative play dimensions with PuppetX. Studies can be done to show if using PuppetX we can increase interaction, creativity, and or social dimensions of play. For example, new kinds of emotionally interactive products can be created. Also of interest is the study of user's feeling and reactions, especially the differences, when playing with virtual vs. physical embodiments of the same objects. The motion and dynamics interpretation can be developed toward making algorithms interpret users intent and unintended motions more robustly and increased controllability, to interact with us in a more natural way. In the future we will conduct studies to validate the control joint mapping, that we discovered from the user study, for ease of use.

In the development of PuppetX framework, we exploit capabilities of motion sensing to detect and track the user's body and finger movements. We are able to involve the users full body during animation, programming and play. By doing so, we create and explore a new form of construct-and-play interface, which has potential for engaging the user(s) and the audience in many new ways. The system uses off the shelf hardware, but develops the algorithms to identify and implement gestures as defined by the users. We have demonstrated different scenarios of use of both the physical and virtual constructs of playthings, including real time play, off line programming and playback, and developed the algorithms to recognize and map gestures in real-time.

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