Towards Tangibility in Gameplay: Building a Tangible Affective Interface for a Computer Game

Ana Paiva, Rui Prada, Ricardo Chaves, Marco Vala
IST-Technical University of Lisbon and INESC-ID
Rua Alves Redol, 9
1000-029 Lisboa, Portugal
ana.paiva@inesc-id.pt

Adrian Bullock, Gerd Andersson
SICS (Swedish Institute of Computer Science)
Box 1263 SE-164 29 Kista, Sweden
adrian, gerd@sics.se

Kristina Höök
DSV, IT-university in Kista
Forum 100, 164 40 Kista, Sweden
kia@dsv.su.se

ABSTRACT

In this paper we describe a way of controlling the emotional states of a synthetic character in a game (FantasyA) through a tangible interface named SenToy. SenToy is a doll with sensors in the arms, legs and body, allowing the user to influence the emotions of her character in the game. The user performs gestures and movements with SenToy, which are picked up by the sensors and interpreted according to a scheme found through an initial Wizard of Oz study. Different gestures are used to express each of the following emotions: anger, fear, happiness, surprise, sadness and gloating. Depending upon the expressed emotion, the synthetic character in FantasyA will, in turn, perform different actions. The evaluation of SenToy acting as the interface to the computer game FantasyA has shown that users were able to express most of the desired emotions to influence the synthetic characters, and that overall, players, especially children, really liked the doll as an interface.

Categories and Subject Descriptors

K.8.0 [**Computing Milieux**]: Personal Computing—*Games*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Input devices and strategies, interaction styles, evaluation and methodology*

General Terms

Human Factors, Design, Experimentation

Keywords

Affective computing, tangible interfaces, synthetic characters

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1. INTRODUCTION

As game development brings us new challenges in the way to involve users in the game, and as characters in these games become more believable and widely used, the interaction between players and those characters will necessarily change. New forms of communication will be explored, influenced not only by face to face communication but also by recent developments in multi-modal communication and tangible interfaces. As users are now able to directly speak to a character, exhibit facial expressions and, through that, influence the behaviour of that synthetic character, computer games will also be a stage for new developments of these new types of modalities in human/computer interaction. In most cases, the interaction between game characters and players presupposes that there is a clear boundary between the character (in the virtual world) and the player (in the real world). The character is "virtual" and its presence is constrained to that virtual world. On the other hand, users can live in two worlds and influence the real and the virtual world [11]. However, despite this dual presence of users, there is still an absence of seamless couplings between these two parallel existences, leaving a great divide between the two worlds (see [4]). This division is behind the growing area of research on "tangible user interfaces" where the goal is to "go beyond the current GUI (Graphic User Interface) and bring current objects to the interaction between users and computers"[4].

Following this vision of interaction we have built an affective tangible interface (SenToy) that allows a player to influence the emotions of his character (avatar) in a 3-D computer game. SenToy works as an interface to the role playing game (FantasyA) where players must exhibit a particular set of emotions and perform a set of actions as a way to evolve in the game (see [11]). Emotions play a central role in the game, since it is through mastering the emotion expression of the controlled characters in the game that players can advance in the game and win battles against their opponents. The aim of SenToy is to "pull the user into the game" through the use of a physical, touchable, affective interface. With sensors in its limbs, sensitive to movement and acceleration, SenToy captures certain pattern of movements that are associated with particular emotional expressions.

Given the novelty of this interaction, to build SenToy we began by investigating if users were able to express a set of

emotions through a toy-like interface. Our main questions were: Can a user control the emotional state of a synthetic character using a physical interface, such as a doll? What kind of gestures would be the best ones to express the set of emotional states we need for the game FantasyA? What type of doll is the most appropriate for this kind of interface?

To answer these research questions we conducted a small Wizard of Oz study (see [1]). The results of this study showed that users were able to learn and express certain emotions through the movements of the doll. However, particular emotions, such as happiness and sadness were more easily performed by the users than others, such as disgust. Based on the results of this early study we developed SenToy, a wireless doll that captures six emotions (happiness, sadness, surprise, fear, gloat, anger) from the user's gestures. Note that disgust has been replaced by Gloat. This was due to the difficulty in detecting disgust, and also takes into account the needs of the game (where gloat was more a appropriate emotion than disgust). SenToy was subsequently integrated with a computer game (FantasyA). FantasyA is a computer game where players must master the control of their character's emotional states in order to influence their actions and thus win the game. FantasyA and SenToy were evaluated with 34 subjects in 17 sessions, subjects playing the game in pairs, and the results show that players liked SenToy as an interface to the game and were able to influence their characters.

This paper describes SenToy and its use as a control mechanism in the computer game. The paper is organised as follows. First we provide a small survey in the areas of tangible interfaces and affective interactions relevant to this work. Next we review our first study concerning the design of SenToy, which determined the way the SenToy looks and the way it captures the emotions from the user. Following this we describe SenToy's architecture, both its hardware and software. Finally we show some of the results obtained in our second study, when SenToy was used in the context of FantasyA.

2. RELATED WORK

The aim of the area of "tangible interfaces" [4] is to move beyond the current dominant model of direct manipulation in Graphical User Interfaces, where computers typically use a rectangular display, windows, a mouse and a keyboard. The idea is to remove the limited communication channels and explore new channels of interaction, such as gestures or touch. Following this idea new types of interfaces have been built, and in particular interfaces with synthetic characters. Objects in the real world can be given extended capabilities that allow users to merge the real world with the virtual world where synthetic characters exist. Of relevance is the work by the team of Synthetic Characters at the MIT Media lab where a "sympathetic interface" [5] was built. In the system Swamped! the user takes on the role of a chicken that is trying to protect its eggs from a hungry raccoon. The user partially controls the synthetic character through a set of gestures representing specific behaviours. For example, the user can wobble a doll back and forth, which will make the virtual chicken walk. Such an interaction device can be viewed as a "physical", "touchable" incarnation of the synthetic character (similar to SenToy). By touching the doll and its physical handling, the user influences the character's behaviour in the virtual world.

In parallel with the establishment of the area of affective computing [12], synthetic characters are also gaining emotional expressions and behaviours, which can be influenced by the user as well. In fact, some systems have already been developed where synthetic characters can be "emotionally influenced" by the user. For example, in the work of [9], users can influence the emotional state of a synthetic dolphin (Isolda) by touching a set of emotional sensors found in a porcelain dolphin placed in a middle of an exhibition room. Also, in an art installation created by N. Tosa [14], users can influence the behavior of two synthetic mermaids through their hand gestures and physiological signals. Each mermaid will move in sync with the user's heart rate (which is captured through an electrode attached to the collarbone of that user).

Aiming at this "emotional influence" through a tangible user interface we have created SenToy.

3. BOOTSTRAPPING THE DESIGN OF SENTOY: A WIZARD-OF-OZ STUDY

People communicate emotion through their body, their gestures and their postures. In fact, the term emotion, comes from the Latin "to move out" suggesting that emotions are manifested in bodily movements and actions.

This fact inspired the design of SenToy as an interface for users to express emotions by projecting some of their emotional gestures through moving the doll in certain ways. This device would establish a link between the users (holding the physical device) and a controlled avatar (embodied by the physical device) of a computer game (in this case FantasyA).

However, to design SenToy we needed to study if and how users could express emotions though the handling of a physical doll. For example, what kind of gestures would be the best ones to express "anger" or "happiness"? Can the users learn certain gestures associated with such emotions? Or are the gestures natural?

Our first inspirational source, to predict the types of gestures users would perform, was some studies on gestures and emotions. These studies show, for example, that high arousal and high intensity are associated with arms held up, away from torso, whereas when the head is down this is associated with negative valence. Table 1 identifies the gestures discovered through this literature search. See [3] for more details. Observations by Kirsch [6] with the "Affective Tigger" suggested that children bent Tigger's head forward to make him sad and bounced him to express happiness. However, how do users respond when controlling an avatar's emotional state through a doll? Do they follow a specific pattern of gestures? As the doll constitutes an intermediary between what the user wants to express and the resulting avatar expression, we cannot expect that users will mimic some kind of "natural" human bodily behaviour. Perhaps users are more influenced by how cartoon characters move, or preconceived ideas of emotions and bodily behaviours?

To answer these questions, and thus inform the design of Sentoy, we performed an initial study using the Wizard of Oz method [1]. In a Wizard of OZ study, a user is made to believe that they are interacting with a system, while in reality the user is interacting with a human Wizard pretending to be the system. In the study, 8 users with ages between 14 and 30, were placed in front of a "controllable" synthetic

character (Papous) and were asked to control the character's emotions through a plush toy. They were told that the plush toy had sensors in its arms and that they controlled Papous, while in reality it was a human "Wizard behind the scenes" who controlled the character Papous. When the Wizard recognised a movement pattern according to the scheme elaborated using emotion theories (shown in Table 1), she made Papous express that emotion.

Emotions	Gestures	Reference
Fear	Put the toy's hands in front of its eyes or moving the toy backwards vigorously	According to [7] fear is associated with avoidance
Disgust	Moving the toy slightly backwards (squeezing it slightly)	According to [7] disgust is associated with "move away", nausea or even vomiting.
Joy	Swinging the toy (making it dance) and/or playing with its arms.	According to Darwin [2], joy is portrayed with open arms and, with movements such as clapping.
Sad	Bend down its neck or bend down all the toy's trunk	According to Scheirer [13] sadness is expressed through slow its arms movement inwards and head down.
Anger	To place its arms crosswise or shake the toy vigorously.	According to Lazarus anger is associated with the "tendency to attack".
Surprise	Open its arms backwards inclining its trunk slightly backwards too.	According to Laban surprise is associated with the inclination of trunk backwards.

Table 1. Table of Emotions and Gestures

When asked to express a specific emotion, users often tried more than one set of movements before the system reacted (when the Wizard recognised the appropriate gesture according to this table). All sessions with the users were video recorded, and questionnaires were made at the end of each session. By analyzing the video footage of each participant we were able to obtain the most common gestures for each emotion for each user. Table 2 shows the number of detected gestures for each emotion as a total of the gestures performed by the users. Note that, given the nature of the experiment, some of the gestures would eventually be learned because of the feedback of the character provided by the Wizard.

Emotion	**Most common gesture**	No.
Fear	Hands in front of eyes	8
Disgust	Arm in front of face as wiping something away	10
Happiness	Dancing and jumping (continuous movement)	16
Sadness	Bending down its trunk	16
Anger	Boxing with its arms	12
Surprise	Arms in air, frozen position	16

Table 2. Most Common Gesture

The results achieved by this experiment (see [11] for more details on the study) show that for certain emotions (happiness, anger, fear, sadness, surprise) there were clear recognizable pattern of gestures that users followed for controlling the emotional state of the character and thus easily picked. We also found that behaviours, such as walk or pick an object, were rated more easily expressed than emotion gestures. Happiness was reported to be almost as easily expressed by most of the subjects. One emotion that was very hard to express was disgust. We also got interesting feedback on how the doll should be designed to best fit with the purpose. Three dolls were tested: a teddy bear, a puppet "Pippi Longstocking" and a SuperModel Barbie Doll Kenneth. Users preferred the soft and cuddly teddy bear rather than the hard plastic Kenneth. They preferred a doll with neutral facial expressions. Finally, its size should be about the size of the teddy bear (about 50cm).

4. SENTOY IMPLEMENTATION

Based on the results obtained by the Wizard-of-Oz test we developed the first prototype of the SenToy, and integrated it into the computer game FantasyA. SenToy is a wireless explicit sensorial interface equipped with three sets of sensors (see Figure 1). The first and most important is the set of accelerometers, which measures the acceleration that the SenToy is subjected to. Such acceleration is measured in three directions (X, Y and Z). The second type of sensor is analogical and used to determine the position of the limbs. The third kind is digital, and used to indicate whether the hands of the doll are placed over the eyes or not. Since the emotions/actions cannot be obtained directly from the rather complex data received from the SenToy sensors, a signal processing module was required and implemented. This module was built to capture the patterns of each of the six chosen emotions.

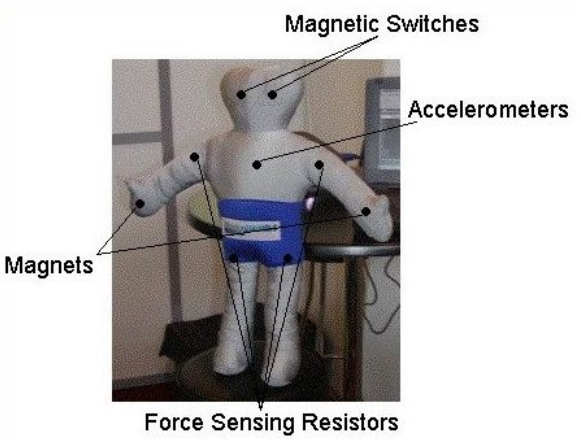

Figure 1: Hardware of SenToy

To understand the methods implemented in the signal processing module, a brief description of the physical characteristics of each emotion will now be presented. Movements are described in 3 orthogonal axes, with the user at the origin. The X axis corresponds to forwards and backwards movements; the Y axis describes lateral, side-to-side movements; and the Z axis corresponding to upwards and downwards movements. We first describe the patterns as they were during the study presented in section 6, and if there have been any then present refinements that have been made since the study. The patterns detected by the signal processing module (shown in Figure 6) are as follows:

Anger The most general form of shaking the doll is to move the doll back and forward in short but fast movements. These movements cause accentuated variations of the

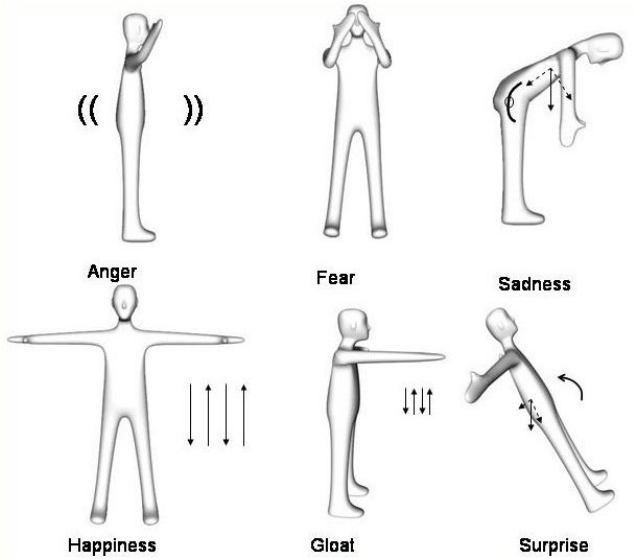

Figure 2: Patterns of movement for the the six emotions.

acceleration value given by the accelerometer on the X axis. Another form of shaking can be produced by swinging the doll along the Y and Z axis. By shaking the doll back and forward the variation of the amount of acceleration on the X axis will increase while in the Z axis will not, which originates a difference between the two accelerations. Further, a difference between X and the Z axis must be detected, in order to guarantee that the movement is being executed only (or at least, mainly) in the horizontal. A minimum oscillation has to be guaranteed in order to consider the movement as shaking.

Our results suggested that the variation of the amount of acceleration by itself is not sufficient to determine the pattern associated with the gesture, but that it is also necessary to observe the position of the doll's arms together with the amount of acceleration caused by the shaking of the SenToy. Therefore in the latest prototype (post evaluation) pattern matching is only completed when the positional sensor in the arms indicate that the arms are up (kind of boxing), a required position to validate the angry emotion.

Fear To detect the gesture associated with fear, the user must put SenToy's hands placed over the eyes, independently of the arms position. From the point of view of pattern recognition, fear is one of the easiest emotion to detect, since the contact of the hands of the SenToy with its eyes is recognized using the electromagnetic sensor(s) placed on the eyes. The contact is recognized as the sensors are near the magnetic field generated by the magnets on the SenToy's hands.

Happiness To express happiness with SenToy, usually the user makes the doll dance and/or jump up and down as a continuous movement (see Table 2). For these movements, the variation of the SenToy's position is predominantly on the Z axis, with wide and rhythmic variation. In order to simplify the emotion detection only up and down movement is considered. The corresponding values along the X and Y axis have to remain low, corresponding to a small movement in both axes. This helps differentiate between anger and happiness.

Sadness The sadness emotion is represented by bending the doll forward, almost to the horizontal plane. This position produces a reduction on the angle between the legs and the trunk. We considered that an angle between 45 and -10 degrees would be suitable for this emotion. In this position, the legs are bent forward, this information is given by the sensors in the SenToy's hips (see Figure 1).

Surprise Unlike the other emotions, the surprise emotion has an asymmetrical sequence of rules, the first corresponds to the movement of jumping back, and the second movement (or lack of it) corresponds to the SenToy laying inclined backwards with its arms open slightly to the back. This movement causes a speed increase on the X axis, this value is observed in the local average value of the acceleration (Na). Note that this value has information about the movement's orientation. After the jump, the doll has to remain with a backward inclination, with its arm open, as illustrated in the Figure 6.

Gloat To express gloating the user has to perform the same gestures as happiness and at the same time point the right arm to the front. This gesture was inspired in cartoon's expressions. As for its detection, we must detect a variation of SenToy's position on the Z axis, with wide and rhythmic variation, together with a movement of the arm of the toy (a pointing expression) detected by the pressure sensors installed in the arms.

Currently only the right arm supports this gesture, though it should be possible to gloat by pointing the left arm. In fact we observed a left handed subject trying to do this in the study.

We end our description of SenToy by considering its look and feel. We decided to make a soft and cuddly toy, rather than the hard plastic one, as the user's preferred this in the first Wizard of Oz study. The SenToys exterior was created using a soft fabric, filled with latex and covered with a kind of skin made with lycra (see Figure 3). Its material and construction took into account: production issues (allow for easy opening of the toy) and also for the way the user will **feel** the toy - allowing for important areas to be marked with a softer material. Inside the doll there is a skeleton made with plastic to hold the sensors in their positions (see Figure 3).

As suggested by the users, we decided that the doll should not have a defined facial expression, character or personality. This way it will not constrain the emotional manipulation, its identification with the user and its adequacy to different synthetic characters. Its minimalist appearance should allow for the same toy to be used for controlling many different types of characters. Given that FantasyA is like an adventure game with emotions, the image of the toy lies somewhere between a toy and an electronic gadget. Its colour and shape reflects this idea.

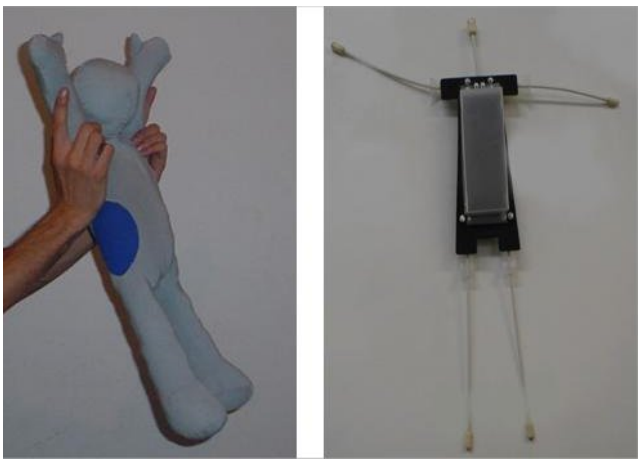

Figure 3: SenToy

5. SENTOY IN FANTASYA

FantasyA is a computer game where users play the role of an apprentice wizard who is challenged to find the leader of her clan in the land of *FantasyA* [8]. The game has an introductory phase, introducing four clans (Air, Earth, Fire and Water), and the duels are explained. Then the player is placed in the *FantasyA World* where she will engage in exploration in order to find her leader.

During that exploration, the player may encounter some opponents against whom she has to fight some duels. The game itself is centered around several duels between the player and computer controlled opponents. However, we intended to move away from the usual control metaphor where players control the actions of their selected characters. The main idea was to enable the player to influence emotions of her character while also taking into account the emotions shown by the opponent. Thus players must master the control of the emotions of their character, and understand the emotional states of the opponents in order to influence the action tendencies and thus cast the appropriate spells for the duel. For example, if the computer controlled character tries to attack the player, but fails, this might result in the player reacting with happiness or gloating, while the computer character might be afraid, angry or surprised. If the opponent is afraid it might make sense for the player to try to attack on her next turn, whereas if the opponent is angry it might be better for the player to try to defend herself. Thus the player must observe what is happening during the duel, and try to influence the outcome through input provided by SenToy, this input being steered by the emotional behaviours being displayed by both players. This is by no means a trivial task, with many rules governing the interactions and reactions between different clans, and we shall discuss this in the results section that follows.

Basically FantasyA has been implemented as a 3D virtual environment using a graphics engine, FantasyA 3D, running on top of OpenGL. This virtual world is populated with embodied virtual characters, some controlled by the system and one by the player. The user is responsible for the emotional state of her chosen character and the others are controlled by the system.

To make the system controlled characters believable and difficult to beat, we followed a simple A* algorithm for obtaining the emotions, taking into account a set of emotion theories such as Lazarus's [7], Ekman [10] and Darwin [2]. Agents follow a set of rules that relate action tendencies and emotions, thus allowing the agent to determine the best emotion for a certain action.

The whole combat is supervised by the combat manager, which monitors the agent's execution and controls the flow of combat and certain cinematic effects. Figure 4 shows the architecture of the system. For example, the combat manager may emphasize certain actions by using a particular camera placing, or use several perspectives to provide a more cinematic effect and thus increase the tension in the gameplay.

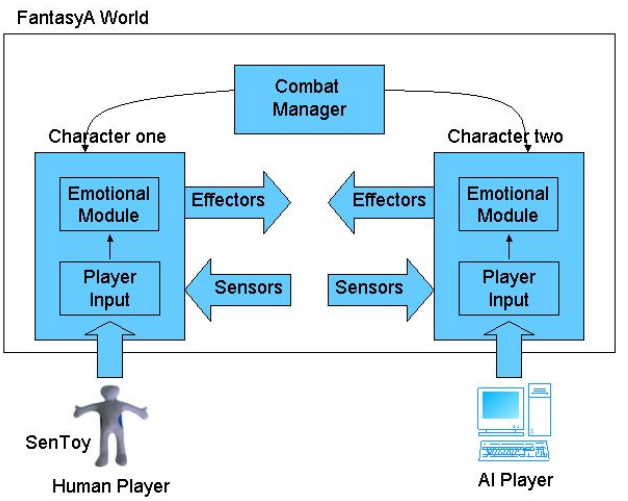

Figure 4: Architecture of the system

Figure 5 shows the example of a turn, where one of the characters, Alvega (the Air character) is casting a spell.

Figure 5: A Duel betweeen two characters: Alvega and Feronya

6. STUDY AND RESULTS

In our most recent study we have been able to use the working prototype SenToy doll to test whether people understand and naturally use the actions and gestures identified in the previous WoZ study, and also to gauge how successful the realised SenToy doll is. The study was performed with 34 subjects and divided into two parts: first we tested the emotion gestures chosen after the previous WoZ study, and second, SenToy was used to play a duel

in the FantasyA game. The first test was performed on an individual basis, whereas the subjects played the game in pairs, sharing SenToy between themselves. This was done to encourage the subjects to share their strategies with each other while playing, as well as mimicing the way that many children play games today with multiple players gathered around playing a single game.

Our subjects ranged in age from 9 to 45 years and can be divided into three main categories: Children, High School Students and Adults. Subjects were first asked to express emotions, one by one, without receiving any prior instructions at all. They were given about 30 seconds to get the right gesture. The system gave feedback through displaying writing which emotion was currently recognised from their actions with SenToy. Concerning the gestures, we reviewed the video footage of each participant, noting when they successfully performed the requested gesture, see figure 6. In many cases the participants were close, sometime extremely, to getting the gesture right, but the movements were not exactly what the sensors were expecting. Alternate gestures, which had been identified in the original WoZ study but had not yet been implemented in the prototype SenToy doll we were using, were also noted.

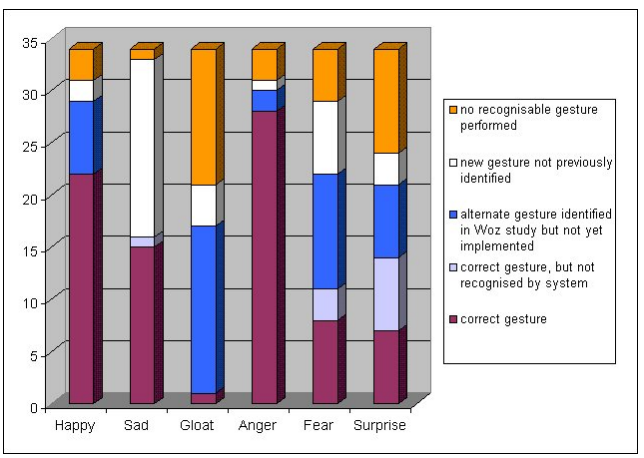

Figure 6: How subjects fared in expression emotions

We can clearly see that the gestures for Happy, Anger and Sad are successful (the significant "other" gesture for Sadness was bending only the doll's head down rather than the body, something suggested in the design of the original WoZ study, but not an observed result from that study). As Gloat was a newly introduced emotion we were not surprised to see people having difficulty, though the current Gloat gesture is a good starting point for identifying an appropriate gesture. As approximately half the users pointed with the doll, but did not "dance" at the same time, it is clear that pointing should be involved in the gloating gesture, but further work is required to refine exactly what this gesture should be. Fear was the most complex emotion, in terms of the different approaches adopted by the subjects. Problems with sensor alignment, together with the diversity of alternate gestures (e.g. running away, sadness, surprise and combinations thereof) means that although the basic gesture is a good starting point, much tweaking and fine tuning is required with this gesture. The task now is to improve the sensor alignment and to decide upon an alternate gesture and support that well. Finally Surprise was arguably the most difficult gesture, requiring a sharp backwards acceleration together with the doll finishing leaning backwards. Many subjects had difficulty performing the gesture even when it was demonstrated to them. This was due to the required accelerational force together with the finishing position.

After this first test phase we explicitly told subjects how to express the emotions, demonstrating each in turn and ensuring that the subjects were able to manipulate the doll correctly. Most of the gestures were easily learnt once they had been demonstrated, with the exception of Surprise. This was particularly tricky to perform given it is a two-part gesture (both rapid movement and finishing position). However, the overall ease with which the gestures were learnt confirms the suitability of SenToy as an interaction device, with the first part of the study providing pointers towards how the (easily learnt) gestures might be refined so they are more natural.

After the instructional session, and users started to play the game for real, the only emotion that was almost entirely avoided was surprise. This can be due to the fact that this emotion did not have a natural place in the game, but we suspect that it was also because it was quite hard to perform. Gloat was used frequently with great success.

6.1 Robustness

SenToy, despite its prototype status, was able to survive two weeks of use with some really rough handling from time to time. Its robustness can probably be improved, but in general the clothing seems to work fine, the skeleton inside the doll did not break, and most sensors survived the shaking and bending. Towards the end of the trial phase we had some problems with sensor calibration, and the accelerometers sometimes stopped working which in turn made the emotion Surprise easier to perform. The arm sensor for gloat sometimes failed near end the end of the trial, but in general people managed.

6.2 SenToy and gameplay

During the game most emotional expressions were very physical and encouraged players to act out the emotion. The exception from this rule was Sad where subjects sat very still, bending the doll over waiting to see the result on the screen. This is not necessarily a bad design choice since sadness is characterised by an inwards posture among people, thus encouraged by the design of the movement. Some users, especially the children, were really keen on having the doll and would pull it from the other player or interfere and try to help the other player in expressing some particular emotion. In the interviews, two children commented that they would have liked to have a doll each and be able to play against each other. Players often got very involved with the doll and the game. Often this was expressed through bigger movements with SenToy. Sometimes these movements would become so exaggerated that the player would have to lean to one side to be able to see what was happening on the screen since the SenToy would be blocking their view (7).

Smaller movements could be associated with less involvement with the game, though sometimes this came when subjects felt more and more assured that they knew how to express a particular emotion. The size of the movements can

Figure 7: Peering round SenToy to see the screen

also be due to the fact that players sat in front of a large screen with lots of space around their chairs. Given a small lap-top, the movements might have been much smaller.

Players sometimes expressed the emotion not only through moving the doll, but also, to some extent, through moving their own bodies. We regard this as a positive sign that we are on the right track in creating a tangible and sympathetic interface for affective interactions and we believe that this could probably be explored even more in subsequent designs.

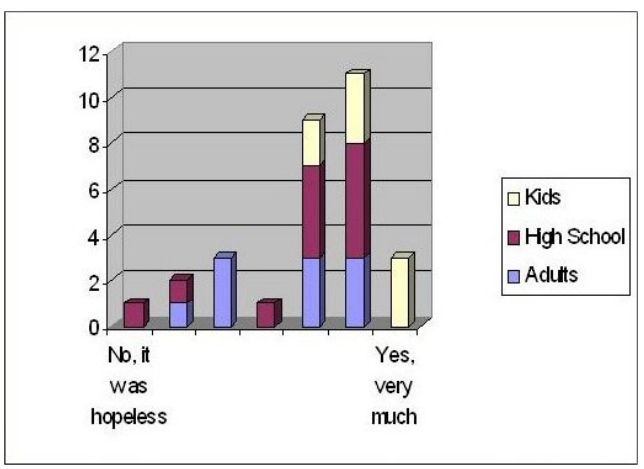

Figure 8: Answers to the question: Did you like the doll?

After the game about 80% seemed to like the doll, see figure 8. The kids were in general more enthusiastic about the doll than the adults.

6.3 Appearance of SenToy

Many players cuddled the doll throughout the interview (after the game). They liked the size, compared it to a child, and seemed to enjoy its weight and design. In the comments field of the questionnaire, one player wrote:

A few days after having played, I still like the doll very much. I really appreciated his direct contact to give commands, even if in that case, the commands were not that obvious and their result a bit fuzzy. (adult player)

One of the kids remarked that he would probably like to use the SenToy for a whole month before getting bored. Considering that he was 12 years old, this is a very good result.

7. CONCLUSIONS

Creating a tangible, sympathetic interaction device such as SenToy for affective input turned out to be both possible and even successful.

The development gained a lot from involved users at an early stage. From literature, only hypotheses for which gestures would be most interesting were gained. In the practical user studies, the actual gestures that worked best with users could be found and tested. The SenToy was subsequently used as part of the FantasyA game and proved to be a much appreciated input device - fully functional and robust enough to be used for several weeks of testing.

In summary, we can say that SenToy was a success. It was robust enough for the experiment, it encouraged a more tactile interaction, players did identify with it, and the size, shape and behaviours were close enough to what they should be. A few improvements can be made (like adjust the signal processing module to capture some of the gestures not picked up and that are easily identifiable). In general we can say that SenToy works as an interface for synthetic characters.

While there is still some fine-tuning to be made, we believe that SenToy can be used in several different interaction scenarios with synthetic characters - ranging from games to training of autistic children. It is not a device exclusively useful in the FantasyA game. In fact, we are now planning to extend it to other types of applications.

8. ACKNOWLEDGMENTS

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