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Applying Scenarios in User-Centred Design to Develop a Sketching Interface for Human Modelling and Animation

C. Mao, S.F. Qin, D.K. Wright, Jun Peng*

School of Engineering & Design, Brunel University, Uxbridge, Middlesex UB8 3PH, UK
*Department of Environmental Art Design, School of Art Design, Tianjin Academy of Fine Arts, PR China

Abstract

This paper presents our user and usability studies for applying scenarios in user-centred design to develop a sketching interface for virtual human modelling and animation. In this approach, we utilise the User Centred System Design (UCSD) strategy and spiral lifecycles to ensure system usability and functionalities. A series of usability techniques were employed. After the initial conceptual design, a preliminary user study (including questionnaires and sketching observations) was undertaken to establish the formal interface design. Second, an informal user test was conducted on the first prototype: a "sketch-based 3D stick figure animation interface". Finally, a formal user evaluation (including performance tests, sketching observations, and interviews) was carried out on the latest version: a "sketch-based virtual human builder". During this iterative process, various paper-based and electronic-based sketching scenarios were created, which were acted-out by users to help designers evoke and verify design ideas, identify users' needs, and test the prototype interfaces in real contexts. Benefiting from applying the UCSD strategy and scenario-based design to develop a natural and supportive sketching interface, our investigation can be a useful instantiation for the design of other sketching interfaces where these techniques have not been widely acknowledged and utilised in the past.

Categories and Subject Descriptors (according to ACM CSS): H.5.2 [Information Interfaces and Presentation]: User centred design, Graphical user interfaces (GUI), Evaluation; I.3.7 [Computer Graphics]: Animation.

1. Introduction

The use of sketching in computer graphics may date back to the seminal SketchPad system [Sut63] in the 1960s. More recently, various sketch-based interfaces have been developed to combine the flexibility and ease of paper and pencil with the processing power of computers to provide an electronic sketching medium that is as natural as paper, yet considerably more interactive and smarter.

In general, a sketching interface should address an application such as user interface design [LM95], geometric modelling [KHR02][IMT99][LS02], animation [DAC*03][HH01][TBP04], etc. During the conceptual design stage, the application needs can orientate a designer's thinking on detailed design aspects, including system pipeline, interaction routine, drawing input/output, design assumptions/questions, etc. Next, a user study needs to be conducted to verify initial design ideas and identify users' needs before formal implementation. In fact, this user-centred system design (UCSD) approach [GGB*06] should be followed early and continuously throughout the entire development cycle. However, there have been few reports on the utilisation of UCSD strategy in sketching interface design, although it has led to the success of many other systems [KKP*04]. In reality, users were often treated as test subjects and involved only at the end of the development process. Although some research has been conducted to study users' needs and sketching behaviours [LQP*04] for interface design, there have been few reports addressing how these research outcomes have been interpreted and implemented. Moreover, the evaluation and real benefits of continuous user involvement for sketching interface design have rarely been acknowledged.

As previously mentioned, a sketching interface is meant to combine the power of paper-based sketching and computer-based automation to provide users with a more natural, functional, and supportive drawing medium. To reach this goal, sketching experimental studies and scenario-based design [Car00][Bød00] are crucial. Only when observing real users performing real tasks in real contexts, can designers verify their design ideas and achieve a deeper understanding of the natural drawing process, users' preferences and needs, and even the problems users may confront during paper-based sketching. Moreover, various scenarios can be set-up at different stages in a user-centred design process for different testing purposes to integrate usability more profoundly into system design [Bød00]. However, little work has been reported on either the application of scenario-based design or the use of scenarios in user centred design for sketching interface development.

In this paper, we present our user and usability studies for applying scenarios in user-centred design to develop a sketching interface for virtual human modelling and animation. Virtual beings play a remarkable role in today's public entertainment, while ordinary users are still treated as audiences due to the lack of appropriate expertise (i.e. mesh modelling, IK/FK), equipment (i.e. 3D body scanner, motion capture system) and computer skills. Our interface enables everyone who can draw to "sketch-out" 3D virtual humans, 2D/3D animation, crowd animation, and character intercommunication.

During the development process, we followed the UCSD strategy and spiral lifecycles to ensure system usability and functionalities. A series of usability techniques were employed. After the initial conceptual design, a preliminary user study (including questionnaires and sketching observations) [MQW06a] was undertaken to establish the formal interface design. Then, an informal user test was conducted on the first prototype: a "sketch-based 3D stick figure animation interface" [MQW05]. Finally, a formal user evaluation (including performance tests, sketching observations, and interviews) was carried-out on the latest interface: a "sketch-based virtual human builder" [MQW06b]. During this iterative process, various sketching scenarios were created, which were acted-out by users at different design stages to orient designers' reflection and action. Our approach entails paper-based scenarios to verify conceptual design ideas and identify users' needs; electronic-based scenarios to test the initial sketching interface with users for further improvements on this interactive drawing medium; and electronic-based scenarios to evaluate usability and functionalities of the fully implemented sketching interface for next iteration development. Through applying scenarios in user centred design, we have achieved a natural and supportive virtual human sketching interface, which is easy to learn and use, and entertaining for a variety of users of different ages, professions, and drawing skills.

2. Related works

Since the 1980s, sketching behaviours and the role of drawing in design [LQP*04][TP03] have been extensively researched. More recently, many sketch-based interfaces have been developed to infuse the advantages of sketching into computer aided conceptual design, such as user interface design [LM95], fast geometric modelling [KHR02][IMT99][LS02], simple animation storyboarding [DAC*03][HH01][TBP04], etc. Very little work, however, has specialised in sketch-based human modelling and animation to create and animate variational 3D virtual beings from freehand figure sketches. Moreover, the principles of UCSD and scenario-based design have not yet been widely acknowledged and practised in current sketching interface design. Although user tests [IMT99][TBP04] and user studies [LQP*04][OSD05] have been carried out, iterative user-centred design processes assisted by various testing scenarios have rarely been utilised or reported in the past.

In terms of sketch-based 3D human modelling and animation, aside from a natural and intuitive interface design, three major challenges exist. They are: 1) how to map from 2D freehand sketches into 3D posed models; 2) how to quickly and automatically animate the reconstructed key frames with little user involvement; and 3) how to generate realistic human shapes from rough figure drawings.

To address the first two challenges, some sketch-based systems [DAC*03][HH01][TBP04] have recently been developed. In Hoshino's intelligent storyboarding system [HH01], the 3D character positions and behaviours are estimated from 2D views using constraints optimization and example-based interpolation. A perspective view is required, together with a pre-built 3D character/scene database. Thorne's "motion sketching" interface [TBP04] enables overall character motions to be specified by cursive gesture drawing. The 2D-3D pose recovery, however, is not addressed by this system, since only side view figure key frames are accepted. Davis et al. [DAC*03] developed a sketching interface for 3D articulated figure animation and presumed a parallel view, which is, in principle, similar to [MQW05]. To solve the "back-front ambiguities" problem (two possible 3D poses exist for each foreshortened bone segment because of reflective ambiguity), a semi-automated method has been used for pose recovery. In this method, all possible figure poses are reconstructed and ranked for user's manual selections. Although this approach supports rapid 3D key framing, rendering information in sketches (i.e. perspective rendering) has not been effectively utilized, which is useful for interpreting the user's intended pose.

In recent years, sketch-based 3D freeform object modelling has become feasible, as demonstrated by [KHR02][IMT99]. In these systems, users draw 2D freeform strokes interactively specifying the silhouette of an object, which is automatically constructed by the system as a 3D freeform surface model represented as polygonal meshes [IMT99] or implicit surfaces [KHR02]. Incremental modelling is supported to assemble and refine the initial objects into final complicated ones through a set of editing operations including extrusion, cutting, blob merging, transformation, etc. The resulting 3D models are mostly stuffed toys, simple clothes, car/furniture models, etc. None of the above systems has embarked on the generation of human skin surface, which is irregular and complicated, thus fairly difficult to model.

3. Conceptual design of a sketch-based virtual human modelling and animation system

In this section, our initial system design is introduced through the following three aspects: 1) Figure drawing sequence, 2) 3D pose reconstruction from 2D stick figures, 3) Free-form skin modelling from figure contour sketching. Design assumptions and questions are raised, as well as the reasons and objectives for the preliminary user study.

3.1. Figure drawing sequence

As stated in [LS02], humans are accustomed to performing the reverse projection of sketched geometries from 2D back into 3D. In terms of the perception of raw figure drawings, the human brain can envision the 3D counterparts easily and even spontaneously. It is, however, mathematically indeterminate and very difficult to emulate computationally. To decompose the complexity of direct 3D modelling and animation from 'noisy' figure sketches (featured by foreshortening, contour over-tracing, body part overlapping, shading/shadow, etc.), we designed a "Stick Figure→Fleshing-out→Skin Mapping" pipeline [MQW06a]. This is inspired by the drawing sequence recommended by many sketch books [Tin92]. In principle, it echoes the animation pipeline in commercial packages (3ds Max, Maya, etc). In this design, the user first draws stick figure key frames to specify a motion. Then, they can "flesh-out" any existing stick figure to portray an imaginary character. The system can automatically reconstruct 3D figure poses and 'perceive' the intended body surface. It can then be wrapped onto stick key poses (akin to clothing wire sculptures), which can be further interpolated as 3D character animation.

Although our initial design enables multiple animation functions and outputs, we were concerned whether the "Stick Figure→Fleshing-out" drawing sequence would be natural and flexible for users. A preliminary user study was needed to evaluate conceptual design ideas, identify user's needs, and seek the optimal compromise between drawing flexibility and system functionalities.

3.2. 3D pose reconstruction from 2D stick figures

As previously stated, 3D pose recovery is one of the primary challenges for sketch-based figure modelling, because of "back-front ambiguities". In reality, humans are able to perceive figure poses from 2D drawings with little confusion. Hence, it is necessary to understand this perception process in order to replicate the effect. At the beginning, we were indebted to the understanding of human physical constraints and depth cues. Since our brain has been trained with natural and possible poses, all abnormal poses are easily excluded. Furthermore, there must be some depth cues in a sketch, which enable observers to reach a consensus without confusion. However, many questions still remained to be addressed from the user study. For example: What types of depth cues are most commonly indicated in figure drawing? What other clues are crucial for sketch understanding? Do people need interactive assistance in figure proportion maintenance, since it is a recognised challenge for not only novices, but also skilled artists?

3.3. Freeform skin modelling from figure contour sketching

As discussed earlier, humans are capable of instinctively perceiving a 'noisy' 2D figure sketch as a realistic 3D body. Thus, understanding this perception process is essential for realising computerised 2D-to-3D reconstruction. Since we see and interact with people, our brain has become familiar with various body shapes and the correlations between 2D flat features and their real 3D counterparts [LS02]. Therefore, when observing a raw figure sketch, our brain can automatically clean up the distracting 'noises', perceive the body size and shape, recall an associated body shape from memory, and then morph and fit it into the 2D drawing to obtain the final 3D image. Theoretically, if given a range of pre-stored morphable template bodies, a computer is able to perform this through performing similar 'thinking', 'recalling', and morphing routines. Moreover, when observing a sketch, our eyes tend to capture a general profile first, followed by more details to depict the surface feature. In terms of sketching, artists usually follow this "coarse-to-fine" routine too. In reality, a computer can support this incremental sketching process in a more interactive and dynamic way. In our proposed system, users can sketch figure profiles to prototype an initial 3D model and incrementally refine it through suggestive contours [DFRS03], shading/shadow, etc, in both 2D and 3D. However, there were still many questions remaining regarding the initial design, such as what degree of sketching inaccuracy and ambiguity our system should tolerate; what the real needs of various users for a natural and supportive sketching environment are; etc. These questions were to be addressed in the following user study.

4. Preliminary user survey study

After the initial system design, we conducted a preliminary user study [MQW06a] to verify design ideas, explore design questions, further identify users' needs, and obtain a true figure drawing story. This user study comprised *Questionnaires* and *Sketching Observations,* which are detailed in 4.1 and 4.2 respectively. In Section 5, an updated system design is presented according to the generalised user study results.

4.1. Questionnaire study and results

A questionnaire was designed and delivered to acquire the basic knowledge of human figure sketching, identify the requirements for developing a "sketch-based virtual human modelling and animation system", and gather users' feedback about the current system design. 60 questionnaires were collected from the research staff and students of the design department, as well as some external artists. The questionnaire consisted of three sections: S1 - General figure sketching questions, S2 - Specific figure sketching questions, S3 - Questions about system development.

In Section 1, *Proportion maintenance, Structure and tension*, *Balance*, and *Unifiability of the human body* were ranked by users as key principles (in descending priority) to ensure a plausible figure drawing.

Section 2 contained two parts. In Part 1, users were asked to choose one or more options from the provided methods for figure proportion maintenance in different sketching scenarios. As shown in Figure 1, the study results are:

- *Measuring devices* are most frequently utilised for proportion maintenance when sketching with models.
- *Sense of feeling* plays an important role in nearly all sketching scenarios, which raises the potential problem of imprecise proportion expression. This problem turns out to be severe when figure sketching without models.
- *Rule of thumb* plays a vital role in each scenario, especially when figure drawing without references.

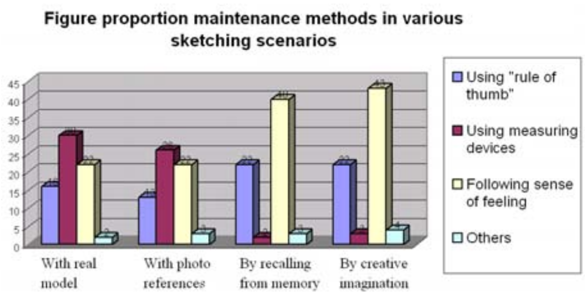

Figure 1: *Figure proportion maintenance methods in various sketching scenarios.*

In Part 2, four questions regarding stick figure drawing were asked to identify *whether* and *how* depth cues are indicated to reveal an intended figure pose. It was presumed that depth cues are often shown as forms of visual contrast (i.e. thickness/size contrast) among different body parts. For instance, artists usually render more strokes on a relatively closer body part to make it visually stronger. In addition, real-time information including stroke speed and pressure may help reveal depth information. Respondents were asked to rank the provided depth cues (or give their own options) in different circumstances. Statistical analysis showed the followings:

- 65% of respondents believe that they often convey figure pose by depth cues.
- *Joint size contrast* (bigger-closer, smaller-further) is the primary clue used to determine the relative positions between pair joints of the same type (e.g. left and right elbow). Other depth cues are ranked as: *Joint thickness contrast*, *Stroke pressure contrast*, and *Stroke speed contrast*.
- *Physical size* is the first priority criterion for varying the sizes of different types of joints, followed by *Joint relative positions*. Moreover, many people chose to vary the joint size randomly, which means size information is sometimes not reliable for pose understanding.
- *Line thickness contrast* (thicker-closer, lighter-further) is chosen as the principal clue to convey relative bone location. Other clues in descending order are *Stroke pressure contrast*, *Stroke speed contrast*, *others*.

From the above results, we can see that depth cues are frequently used for pose indication. Different depth cues (i.e. thickness/size contrast) are used in different circumstances. Confusion may arise when multiple factors (i.e. physical size, spatial distribution) work together to affect joint size variation. Therefore, sketching observation was needed to acquire real-time solutions for these mixed conditions.

In Section 3, users' expressed opinions regarding the initial system design:

- 85% of respondents accepted our figure drawing sequence design: "stick figure → fleshing-out".
- 95% of respondents agreed that the system should be able to provide drawing assistance for figure proportion and foreshortening maintenance.
- 90% of respondents agreed that the system should 'perceive' depth cues for pose recognition.

In Section 3, we also set an open question to enquire about users' requirements for a virtual human sketching system. The summarized answers are integrated in Table 2.

4.2 Sketching observation study and results

Apart from the questionnaire study, sketching scenarios were designed to obtain a real-time story from users when they perform paper-based drawing tasks. Sketching observations were conducted to obtain both static (figure sketches) and dynamic (natural sketching behaviours) information in the pre-defined scenarios.

4.2.1 Participant selection

Nine participants were involved in sketching observations. The participants were from various professions including artists, designers, graduate students, and researchers. Their sketching skills varied from excellent to poor.

4.2.2 Sketching interview and sketching scenario design

The sketching interview comprised 3 stages. In Stage 1, the participants were introduced to our proposed system and the interview programs. In Stage 2, the participants were asked to sketch in three different scenarios:

Scenario 1: *Stick figure drawing with photograph references*

Participants sketch-out stick figures (3-4 expected) within 8 minutes by referring to figure photos provided.

Scenario 2: *Fleshing out with photograph references*

Participants choose one or more stick figures sketched in Scenario 1 for fleshing-out within 10 minutes. They are permitted to flesh-out details (i.e. character clothes/face, suggestive contours, shading/shadow) at their discretion.

Scenario 3*: Key frame drawing without references*

Participants draw stick figure key frames (3-4 expected) to express an imaginative motion within 4 minutes.

Scenario 1 and Scenario 2 corresponded to the *stick figure drawing* and *fleshing-out* routines in our initial design. Here, the time limit was designed to simulate a fast sketching process, which was video recorded and closely observed. A series of observation criteria were established to explore design questions and obtain a figure drawing story in real contexts. Moreover, sketching observations were aimed to investigate the nature and limitations of a paper-based drawing medium to help build a more natural, functional, and supportive electronic drawing medium. 7 indexed photo references in 3 groups were selected to represent variations of body shapes. Multiple conditions including foreshortening and body part overlapping were covered in the photo references. Stage 3 aimed to gather users' feedback/suggestions regarding the prototype system design.

4.2.3. Sketching observation criteria design

The observation criteria were designed to unfold a "real story" of figure sketching in the pre-defined scenarios. The criteria and their associated meanings are listed in Table 1. The observation results follow in the next section.

Table 1: Sketching observation criteria design

Observation criteria	Meanings
C1 Sketching tools	To analyse the use of Wooden pencils (HB-6B) and an eraser for evolving the interface tool set.
C2 Drawing modification	To determine the modification means supported by the prototype system.
C3Proportion/Foreshortening	To gather real-time information regarding *how* people maintain proportion and foreshortening during figure sketching, and *what* problems they frequently confront.
C4 Depth cues	To reveal *whether* and *how* participants indicate depth cues to convey an intended figure pose
C5 Sketching procedures	To investigate the compatibility of the "stick drawing → fleshing out" sequence and the whole fleshing-out process.
C6 Stroke types	To identify rendering stroke types.
C7 Fleshing-out details	To examine the sketched relationships between stick lines and body contours.
C8 Reference lines	To assess whether or not reference lines are used to assist the figure sketching.
C9 Annotations	To determine if annotations are denoted and needed to be accepted as sketching inputs.

4.2.4 Sketching observation findings

Nine sets of *stick figure drawings* with associated *fleshing-outs* and 6 *key frame sketches* were recorded and analysed. Figure 2 shows some selected sketches including stick figure drawings, fleshing-outs, and key frame drawings.

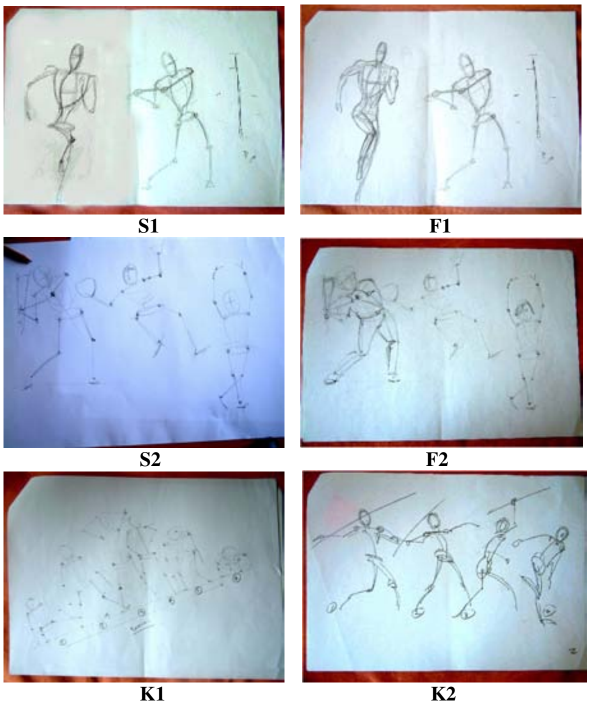

Figure 2: *Selected sketches from a designer (S1, F1), a graduate student (S2, F2, K1), and an artist (K2).*

The observation results are given below.
R1. Sketching tools: During sketching, almost all participants persisted with the same sketching tool that they had picked up at the beginning. This suggests that varying the sketching tool for certain rendering purposes is not imperative for quick sketching.
R2. Modification during sketching: Modification was made more frequently during the *fleshing-out* process. Participants sometimes performed over-tracing (see Fig 2(F2)) rather than "erasing + redrawing" to modify an existing sketch.
R3. Proportion/Foreshortening: Within a time limit, most participants sketched cursorily, even with photo references. The resultant sketches were therefore mis-proportioned (see Fig 2(S1/F1/K1/K2)), and appeared to run off the paper (see Fig 2(S1/F1)). Therefore, real-time assistance is required for supporting proper figure drawing.
R4. Depth cues: We marked the foreshortened body parts of each photo model and evaluated the usage and forms of depth cues through analysing the corresponding figure sketch. Through observation, it seemed that depth cues were frequently delineated even on a simple stick drawing, through visual contrasts of size or thickness (see Fig 2). In more detail, thickness contrasts (see Fig 2(S1/F1/S2/K1)) appeared more often than size contrasts (see Fig 2(K2)), which were varied almost randomly without following any apparent rules. This conflicted with the questionnaire study results, where size contrast was preferred. Since the latter came from real sketching, thickness contrast was adopted as the depth cue for pose identification in the prototype system. Moreover, since rendering styles varied among individuals, the depth meaning implied by a given thickness contrast was not exclusive. Hence, rendering gestures might need to be generalised. In addition, no distinctive correlations between stroke speed/pressure and depth meaning could be recognised.
R5. Sketching procedures: We observed that participants seemed to tune into the "stick drawing → fleshing out" routine smoothly, especially the professionals and intermediate users who appeared familiar with this sequence. Novices required several attempts before becoming skilled. In *Scenario 2*, participants usually fleshed-out stick figures layer-by-layer according to the degree of detail. Moreover, in *Scenario 3*, key postures were sometimes drawn first followed by supplemented in-betweens.
R6. Stroke types: Participants usually drew body contours and shading by multiple strokes instead of a single stroke. Figure contours were sometimes partially missing due to a specific view (i.e. side view), body part overlapping, etc. Every sketch had more or less imperfections depending on participants' drawing skills (see Fig 2). Thus, the system has to tolerate these types of ambiguities and imprecision to keep the sketching process natural and flexible.
R7. Fleshing-out details: When fleshing-out, the professional/intermediate (see Fig 2(F1/F2)) were normally able to treat initial stick lines as a real skeleton and incorporate body contours properly. Novices sometimes drew figure contours fused with stick lines due to limited knowledge of human anatomy. Thus, the system should provide some supportive functions.
R8. Reference lines: Some participants first drew reference curves, which they called "major dynamic lines" to show a big figure profile. Reference lines such as "proportion lines" (Fig 2 (S1/F1)) were used to help maintain figure proportion.
R9. Annotations: Annotations were frequently drawn during key frame sketching (see Fig 2(K1/K2)) to denote key frame indices, the sketch title, etc.

5. Updated system design based on user study outcomes

After the user study, our initial system design was updated (see Table2) to reflect the key points learned from the survey.

Table 2: The updated system design

Accepted design	**Amended design**	**Newly integrated design**
1) "Stick figure→Fleshing-out→skin mapping". 2) "On-line drawing assistance". 3) "Coarse to fine" drawing routine. 4) Accept various rendering forms, strokes, reference lines, and annotations. 5) Tolerate drawing imperfections. 6) Provide various modification methods. 7) Perception-based 3D skin modelling. 8) Interactive sketching in a 2D/3D mixed environment.	1) Thickness contrast is taken as a primary depth cue. 2) Generalised depth gestures are employed to correlate between 2D visual contrast and 3D depth meanings. 3) Depth cues, human body physical constraints, and key frame coherence are incorporated together for 2D-3D pose recovery	1) Sketch-based motion specification. 2) Functions to create a personalised 3D virtual world. 3) Display 3D figure models on a virtual floor. 4) 2D/3D models and animations in both PR and NPR format. 5) Functions to allow detailed character manipulation (i.e. face/clothes editing).

6. Implementation of the prototype system

Based on the validated design, we developed a "Sketch-based Virtual Human Modelling and Animation System", with two releases: 1) "Sketch-based 3D Stick Figure Animation Interface", and 2) "Sketch-based Virtual Human Builder". In this section, we present the implementation details and function highlights of these two linked systems and an informal user test on the stick figure animation system. The testing results contributed to the development of the latest virtual human sketching interface.

6.1 Implementation of a sketch-based gesture interface for 3D stick figure animation

We developed a sketch-based gesture interface [MQW05], which enables users to "draw" 3D stick figure animations. It allows users to interactively sketch stick figure key frames, graphically define motion path and timing, and finally "pop-up" 2D characters into 3D animations with a single click.

6.1.1 Sketch stick figures with on-line drawing assistance

As shown in Figure 3, users can convey imaginary motion by sketching stick figure key frames. In our system, on-line drawing assistance is provided to help maintain proper figure proportions and foreshortening. Users sketch each body part as a single stroke line, which automatically snaps to the adjacent one to ensure connectivity. Like artists refining their figure drawings by incrementally adding details, users can render extra strokes on drawings at any time to indicate depth information when posing a figure.

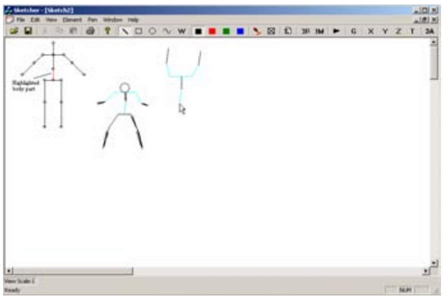

Figure 3: *The sketching interface with template skeleton and freehand figure sketches: Users can choose/create a template skeleton as a drawing reference. The bone segment being drawn is recognised and highlighted on the template. Its maximum length is confined by the template length. Foreshortened and non-foreshortened segments are distinguished in black and green respectively. Perspective effects are rendered incrementally by multiple strokes.*

6.1.2 Reconstruct 3D figures from 2D freehand drawings

For 2D-3D pose recovery, we developed a "multi-layered back-front ambiguity clarifier", which utilises figure perspective rendering, human joint Range of Motion (ROM), and key frame coherence to identify the user intended 3D poses. To unify the correlations between bone/joint thickness contrasts and their depth meanings, we have generalised a set of rendering gestures, which is easy to learn and efficient for pose inference by system. Generally, the thicker bone/joint is the closer (see Fig 4(Left)). Our system supports an interactive design process, through which 3D figure models can be viewed and updated in response to user's incremental sketching (see Fig. 4(Top right)). In addition, a "figure pose checking/auto-correction" routine is offered to ensure physically valid poses during a fast sketching process (see Fig. 4(Bottom right)).

6.1.3. Sketch-based 3D animation and motion control

Once a series of reconstructed figure key frames are obtained, the final 3D animation and motion control can be accomplished by interactively sketching-out the motion paths and keyframe timing (see Fig 4(Left) and 7(Bottom left)) Moreover, users can choose/add their personalised music and panorama to enhance the 3D virtual world (Fig 7(Bottom right). The resulting animation is synthesised in VRML and can be triggered by a single user click.

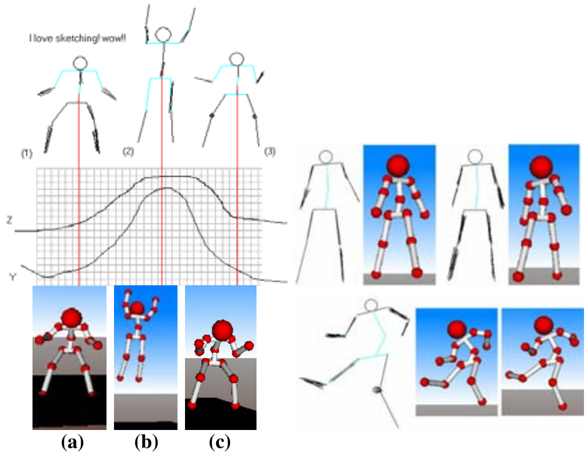

Figure 4: *(Top left) 2D key drawings and motion curves to define a jumping action; Annotations are added to denote the drawings; (Top right) After incremental sketching, the figure pose is changed according to the modified perspective rendering; (Bottom left) The sketched-out 3D jumping motion; (Bottom right) An original drawing with its ill-posed and auto-corrected 3D figure models.*

6.2 Informal user test on the first prototype interface

After the implementation of the sketch-based 3D stick figure animation interface, we conducted an informal user test to evaluate its functionalities and usability, and identify users' new needs introduced by this digital drawing medium. The participants included some internal research staff and graduate students in the design department. After a short tutorial, users were required to sketch-out simple three-framed stick figure animations using our system via a pen-based Tablet PC. Users were closely observed performing drawing/animation tasks on this digital drawing medium. During the test, users rapidly learned the modelling and animation routines, and drew-out their own 3D animations within minutes. Regarding our sketching interface, users considered it to be as natural and flexible to use as paper, yet considerably more functional and amusing to "pop-up" 2D drawings into 3D animations with minimum non-sketching interaction. Our on-line drawing assistance seemed beneficial for users during fast figure sketching. Based on sketching observations and users' feedback, further development aspects were summarised:

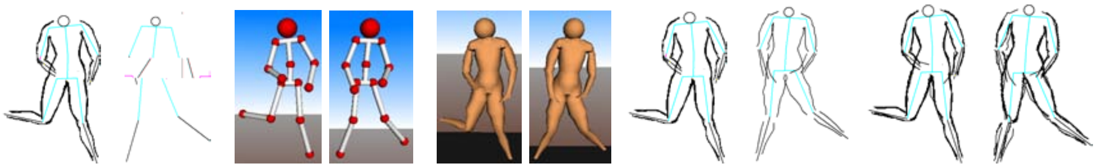

Figure 5: *Users first draw stick figure key frames to define a specific motion. Then, they can "flesh-out" any existing stick figure with body profiles. The system can automatically "perceive" the body size and shape from the sketched figure and transfer it into a plausible 3D human model. It can be mapped onto posed stick figures, which can be further interpolated as 2D and 3D animations.*

- Adopt meaningful graphical icons associated with the existing text to distinguish different function buttons.
- Produce more varieties of sketch-generated characters including 3D mesh models, 2D NPR figures models, etc.
- Integrate libraries of sketch-generated motions and characters in the system for easy saving and retrieving.
- Enable motion retargeting for reusing previous motions and characters to generate new animations.
- Enable sketch-based crowd animation and 2D storyboarding of 3D character intercommunication.

6.3 Implementation of a sketch-based virtual human builder

Through incorporating users' feedback into the initial system design, a "sketch-based virtual human builder" [MQW06b] was designed. It enables users to sketch-out and animate virtual humans of variational body sizes, shapes, and fat distributions. Its graphical pipeline is shown in Fig 5.

6.3.1 Creative model-based 3D body generation method

Users can depict the visual appearance of a virtual character through "fleshing-out" a single stick figure with body profiles. We investigated a "creative model-based method", which can perceive the body size and shape of a sketched figure and transfer it into a plausible 3D human model, through continuous graphical comparisons and generic model (The Visible Human Project®) morphing (rigid morphing→fatness morphing→surface fitting).

6.3.2 Transfer 2D freehand sketches into 3D plausible human body models

Our system can process and transfer a 'noisy' figure sketch of multiple strokes, missing contours, and asymmetry into a plausible 3D body model. An "auto-beautification" option is offered to regularise an asymmetrical human body caused by users' drawing imperfections. Moreover, users can interactively refine the resulting 3D model by over-sketching 2D figure profiles. Modifications can be made freely on any key frame sketch to obtain the updated model. Enabling 2D/3D mixed figure drawing is our next challenge.

6.3.3 Generate 2D and 3D virtual human animation

Our current virtual human builder generates various animations including articulated figure animation, 3D mesh model animation, 2D contour figure animation, and 2D NPR animation with personalised drawing styles.

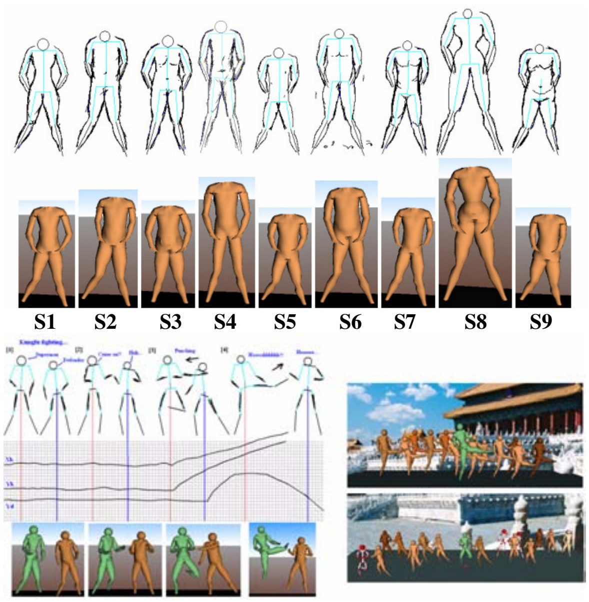

Figure 6: *(Top) A variety of 3D virtual humans and the original drawings by different users: artist (S3), design student (S4), animator (S6, S7), graduate students (S1, S2, S5, S9), and a child (S8); (Bottom left) The Kungfu storyboards with associated dialogues and motion curves, and the 3D fighting characters; (Bottom right) Kungfu group animation with music and background; A crowd of sketch-generated virtual humans and stick figures are fighting with each other in a 3D virtual world.*

6.3.4 Sketch-based crowd animation and storyboarding of 3D character intercommunication

In our system, users can build their own 3D character and motion library, and animate a population of virtual humans (Fig 6 (Bottom right)) through motion retargeting and sketch-based actor allocation in 3D space. Moreover, users are able to illustrate character intercommunication and script dialogue in each story scene, through either stick or full figure drawing. (Fig 6 (Bottom left)).

7. Formal user test on the latest sketching interface

On the completion of the current virtual human modelling and animation interface, we conducted a formal user evaluation to assess its usability and functionalities with various users through performance tests, sketching observations, and interviews. Ten users were involved in this evaluation: 5 design students, 1 engineering student, 1 social science student, 1 artist, 1 animator, and 1 twelve-year-old boy. None of them had been involved in our early user tests. Only the animator had previous experiences with 3D character modelling and animation.

7.1 User test procedures

During the test, the user was first given a briefing (5 mins) about system aims and functionalities. Then, a demo (15 mins) was provided on how to use our sketching interface to create stick and full figure animations. After that, the user was allowed to run the program for 5 minutes to become familiar with it. Then, each user was requested to sketch-out 3D animations in the following two scenarios:

Scenario 1 – Users sketch-out a 3-frame stick figure (SF) jumping animation on a Tablet PC.

Scenario 2 – Users sketch-out a 3-frame full figure (FF) Kungfu animation on a Tablet PC.

The 3D key poses (SF–jumping, FF–Kungfu) were pre-defined and shown to users, so that they could depict them through 2D sketching to achieve similar results. The evaluator timed and observed every individual task. After the performance test, user interviews were conducted.

7.2 Performance test results

After minimum training, the overall average time for creating a complete SF and FF animation was 6.27 mins and 6.75 mins respectively. Regarding animation speed and quality, the top 3 users were the animator, the artist, and a design student. This reveals that our sketching/animating routine is similar to their real practice. It was delightful to see that the young boy (12 years old) could sketch-out SF and FF animations enjoyably in just 6.5 and 8.34 minutes. From the stick figure to the full figure section, users' average time on each individual task was noticeably reduced as: *key framing* (2.54→2.51 mins), *depth gesture indication* (1.50→1.05 mins), *3D reconstruction* (0.93→0.59 mins), and *motion definition* (1.30→0.67 mins). This suggests the prominent learnability of our system to allow users to incrementally master it through previous usages. Users' average fleshing-out time was only 1.93 mins, which is even quicker than that of paper-based drawing. All created models were integrated into Fig 6 group Kungfu animations shown in Fig 6.

7.3 Sketching observation and interview results

Through observation, it was found that users drew figure key frames quickly and freely as if drawing on paper. The "on-line drawing assistance" appeared to be useful and supportive during a fast sketching process. The depth indication gestures were intuitive and logically understandable, although users sometimes needed to pay extra attention to imagine proper thickness contrasts to depict a relatively complex 3D pose. Users performed the "stick figure→fleshing-out" routine smoothly and efficiently. The fleshing-out process was flexible and interactive assisted by auto-beautification and incremental drawing functions. Regarding 3D reconstruction and animation production, users interacted with interface toolkits fluently with the assistance of associated graphical icons. The graphical motion specification is simple and intuitive, whilst direct 3D path editing is required for more precise motion definition. During interviews, users recommended a 3D pose window to show immediate 2D depth rendering results. The artist suggested more surface depiction forms, such as shading/shadow, suggestive contours, etc. The animator recommended commercial tools to refine the sketch-generated models and motions to meet practical needs.

8. Conclusion and future work

In this paper, we have presented our user and usability studies for applying scenarios in user-centred design to develop a sketching interface for virtual human modelling and animation. User centred design and spiral lifecycles are common practice for software development. Few reports, however, have addressed their application in sketching interface development to fulfil both users' needs and system functionalities. A sketching interface is meant to combine the power, as well as minimize the disadvantages of paper-based sketching and computer-based automation to be a better drawing medium. Constant sketching experiments and scenario-based design are therefore crucial to identify the nature of drawing and users' evolving needs on paper-based and especially computerised tools to accomplish an optimal interface. In our approach, we employed various scenarios throughout the user centred design process and achieved a novel interface, which enables virtual human modelling and animation through natural and supportive 2D sketching. Benefiting from applying the UCSD strategy and scenario-based design in real practice, we hope that our investigation can be a useful instantiation to enhance the design of other sketching interfaces. In the future, we will adhere to our user-centred approaches and continuously improve our sketching interface according to users' needs.

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