Sketching-out Virtual Humans: From 2D Storyboarding to Immediate 3D Character Animation

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ABSTRACT
Virtual beings are playing a remarkable role in today's public entertainment, while ordinary users are still treated as audiences due to the lack of appropriate expertise, equipment, and computer skills. In this paper, we present a fast and intuitive storyboarding interface, which enables users to sketch-out 3D virtual humans, 2D/3D animations, and character intercommunication. We devised an intuitive "stick figure→fleshing-out→skin mapping" graphical animation pipeline, which realises the whole process of key framing, 3D pose reconstruction, virtual human modelling, motion path/timing control, and the final animation synthesis by almost pure 2D sketching. A "creative model-based method" is developed, which emulates a human perception process, to generate the 3D human bodies of variational sizes, shapes, and fat distributions. Meanwhile, our current system also supports the sketch-based crowd animation and the storyboarding of the 3D multiple character intercommunication. This system has been formally tested by various users on Tablet PC. After minimal training, even a beginner can create vivid virtual humans and animate them within minutes.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: Graphical User Interfaces (GUI); H.1.2 [**User/Machine Systems**]: Human Information Processing; I.3.7 [**Computer Graphics**]: Animation.

General Terms
Design, Verification.

Keywords
Storyboarding, human modelling and animation, sketching interface, character intercommunication.

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1. INTRODUCTION
Since the advent of the first computerized human models [1] in 1970s by aeroplane and car manufacturers, human modelling and animation have involved constant effort and extensive research from computer scientists for many decades. Nowadays, its application has penetrated into a great variety of fields, such as industry, military, biomedicine, education, etc. In today's public entertainment, virtual beings are playing a particularly remarkable role, when engaged in 3D games, Hollywood films (e.g. "The Lord of The Rings", "Star Wars", "The Incredibles", etc) and multimedia (virtual TV presenters). However, creating 3D characters and their animations is, by far, still remaining the domain of professionals. Although impressed by the marvelous visual impact, ordinary people are rarely given the chance to participate, due to the lack of appropriate expertise, equipment, and computer skills.

At present, the typical CG animation pipeline entails the preproduction (scriptwriting, storyboarding), production (modelling, rigging, scene layout, animation, rendering, etc), and postproduction (composing, video editting, etc) [2]. In general, creating a CG character animation is an extraordinarily demanding job, which requires a great deal of time, equipment, expertise, and often the collaborations among various specialists and production teams. During the above process, although 2D storyboarding, as a classical animation tool, is relatively simple and intuitive for the novice to organise scenes [3], the subsequent technical tasks are always too overwhelming and unachievable for ordinary users.

To bridge this gap, we developed an intelligent storyboard, which enables each one who can draw, to "sketch-out" 3D virtual humans, and their animations, as well as intercommunication. Through our interface, users can depict the character actions by drawing simple stick figure key poses, with graphical motion paths and timing, which can be automatically reconstructed as continuous 3D motion. Then, users can "flesh-out" any existing stick figure with body profiles to portray the appearance of their imaginative character. The system can automatically "perceive" the body size (skeleton proportion) and shape (body profile and fat distribution) from the sketched figure, and transfer it into a

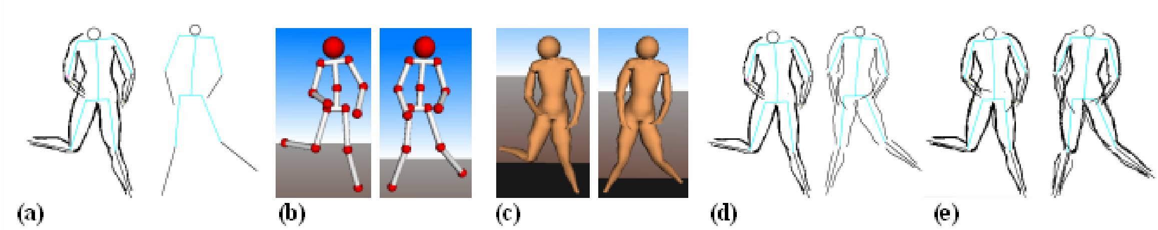

Figure 1. Sketching out a virtual human and animating it in both 2D and 3D world.

characteristic 3D virtual human model. This resulting skin surface can be then mapped onto each of the posed stick figures, which can be further interpolated as a variety of 3D and 2D character animation. Meanwhile, users can build their own 3D character and motion library, and animate a population of virtual humans through motion retargeting and a sketch-based actor allocation in 3D space. Moreover, users are also able to sketch-out the intercommunication among multiple characters in each story scene. The system can deliver an immediate 3D scenario, in which virtual actors are acting and intercommunicating with each other.

The rest of the paper is organised as follows: Section 2 summarise the previous works in related areas. In Section 3, we brief our sketch-based human modelling and animation pipeline first, followed by some details on stick figure keyframing, sketch-based motion path and timing control, graphical virtual character generation, and multi-level animation creation with synthesised panorama and sound/music. In Section 4, we elaborate on how users can animate a virtual human population, through motion retargeting and the sketch-based scene layout. In Section 5, we present the 2D storyboarding for the 3D multiple character intercommunication. Section 6 contains some implementation details and user experiences of the current storyboarding interface. In Section 7, we conclude this paper with some discussions and ideas for future work.

2. RELATED WORKS

Human modelling and animation is an essential theme of modern computer graphics, which has drawn remarkable attentions from the academic and industrial communities for over thirty years. The research in this area encompasses the development of numerous techniques: human body shape modelling [2][4][5][6][7][8], motion control of articulated figures [9], skin deformation [10], facial animation [11], task level and behaviour animation [12], etc. In terms of the virtual human generation, three major categories can be identified. They are: creative [2][4][13], reconstructive [5][6][14], and interpolated [7][8]. In general, the purpose of all these current works is to generate 3D human body models effectively and efficiently to meet the practical needs of the film industry, 3D game, multimedia, virtual reality, etc. Although capable of creating highly realistic human body models with variational appearances and motions, these approaches generally require the extensive expertise, special equipment (traditional camera, video camera, 3D body scanner, motion capture system, etc), and proficient computer skills. Therefore, regular users are still treated as audiences, and have rarely been given the chance to create and animate their own virtual characters, due to the lack of appropriate expertise, equipment, and computer skills.

At this time, many researchers have recognised the intuitiveness and importance of sketching, as a design tool, to bring common users into 3D modelling and animation world with ease and fun. Since Teddy [15]'s birth in the late 1990's, sketch-based 3D freeform object modelling becomes feasible and an increasingly hot research issue. Many works [16][17][18] have been developed to transfer the user's 2D freehand drawings into 3D freeform surfaces (i.e. implicit surface, convolution surface, polygonal mesh) of stuffed toys, simple clothes, car/furniture models, etc, in various manners. Sketch-based 3D human body modelling, however, has still remained a difficult undertaking, which has rarely been addressed in the past. Since the human being is a very complex object and our eyes are especially sensitive to the human figure, current modelling techniques constrained by a spherical topology as in [15][16][17], are essentially not adequate for obtaining the plausible results.

In recent years, sketch-based 2D/3D animation is growing rapidly as an interesting and promising research area. Several sketching interfaces have been developed for articulated figure animation [19][20], motion doodling [21], and cartoon storyboarding [3]. Meanwhile, another corpus of research work have been specialised in infusing the expressiveness of traditional 2D animation into 3D animation, through cartoon capture and retargeting [22], motion stylisation [23], and view-dependent animation [24]. Although impressive, many of these systems [3][19][21][23] are only dealing with single and simple character in each animation, rather than the sophisticated human characters with realistic appearances and variational actions. While essential for storytelling, the intercommunication among multiple actors has rarely been supported. Meanwhile, none of these systems has delivered a complete picture of the "sketch-based modelling and animation", including key framing, figure pose recognition, 2D-3D surface modelling, and the resulting animations performed by various levels of characters (e.g. stick figures, 3D mesh models, 2D NPR models, etc.)

3. SKETCHING-OUT SINGLE CHARACTER ANIMATION

3.1 Sketch-based human modelling and animation pipeline

As in [25], a sketch is essentially a noisy projection of a 3D object onto an arbitrary plane, and the reconstruction is an inverse projection of the sketched geometry from 2D back into

3D. In terms of the perception of raw figure drawings, the human brain can envision their 3D counterparts easily, and even spontaneously. This is, however, rather difficult to be performed by computer, especially when provided with a drawing that has many 'noises', such as, foreshortening, contour over-tracing, body part overlapping, shading/shadow, etc.

To decompose the complexity of the direct 3D modelling and animation from fully rendered sketches, we have designed a "stick figure [20]->fleshing-out->skin mapping" pipeline (as illustrated in Figure 1). This was inspired by the drawing sequence recommended by many sketch books and tutorials [26][27]. Meanwhile, it principally echoes the prevalent CG animation pipeline, whilst employed instead in a sketch-based intuitive way. On this sketching interface, users draw stick figure key frames first to define a specific character motion. Unlike a common character choreography, these illustrative sketches can be automatically reconstructed by the system as immediate 3D motion (see Figure 1(b)), which remits the additional 3D key framing job by users. Then, users can choose a single stick figure for "fleshing-out" (see Figure 1(a)), which is akin to the character visual appearance design. The system can "perceive" the body features of the sketched figure, and "pop-it-up" into its counterpart 3D character directly, which effectively relieves users of the tough and time-consuming 3D modelling task. After that, users do not need to perform the character rigging. The system can automatically "wrap" a single skin surface onto a series of posed stick figures and interpolate them as the final 3D full figure animation (Figure 1(c)). Moreover, 2D contour animation (Figure 1(d)) and 2D NPR (Non-Photorealistic Rendering) animation (Figure 1(e)) could also be delivered with a personalised sketchy look.

Regarding our current design, the functionalities at different levels were achieved for different users. Thus they can choose to make simple stick figures, create delicate 3D surface models, or explore further to animate these sketch-generated creatures. Moreover, models could be exported to commercial packages (3D Studio Max, Maya, etc.) at any level, to be refined by their powerful function kits.

3.2 Sketching-out 3D stick figure key frames and animation

As shown in Figure 1(a), users can convey a specific character motion by simple stick figure drawings. In our storyboarding system, an on-line drawing assistance is provided to help users maintain the proper figure proportion and foreshortening. For 2D-3D pose recovery, we developed a "multi-layered back-front ambiguity clarifier" [20], which utilises figure perspective rendering, human joint ROM (Range of Motion), and key frame coherence to identify the user intended 3D poses. In addition, a "figure pose checking/auto-correction" routine is offered to ensure the physically valid poses. Moreover, we support a sketch-based interactive motion path and timing control (see Figure 8(top)) [2][21]. Sound/music and panorama (see Figure 5(Top), Figure 7-9) have been provided to enhance the 3D virtual world. Alternatively, users may import their own selections. The resulting 3D stick figure animation is synthesized in VRML, which can be triggered by a single user click. The technical details have been presented in [20].

3.3 Sketching-out variational 3D virtual human bodies

3.3.1 Creative model-based 3D body generation scheme

As early introduced, users can depict the visual appearance of their virtual character through "fleshing-out" a single stick figure with body profiles. We developed a "creative model-based method", which emulates a human perception process to generate the variational 3D human bodies from 2D freehand sketches, through morphing a pre-stored 3D generic model. Our generic model is created from an anatomical image dataset [28], which has been encapsulated with three distinct layers: skeleton, fat tissue, and skin. Figure 2 illustrates this computer-simulated 2D to 3D perceptual process. Since only one generic model is employed, our current system could not generate a full range of population (including female, children, elders, etc). This, however, can be solved in the future by creating a wide range of morphable template bodies for modelling use. The sketch-based modelling of human heads/hands/feet is not feasible at this stage, which is also a common challenge for other related approaches.

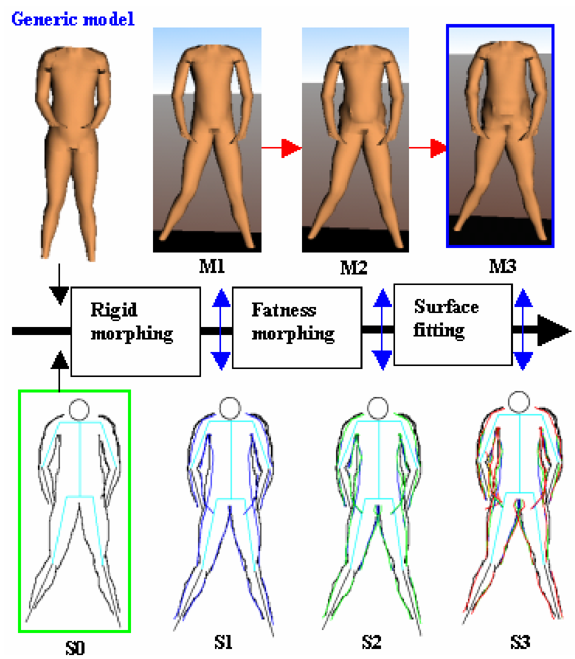

Figure 2. Transfer a 2D freehand sketch into the 3D body model through an automatic system perception and morphing process: Users draw a 2D figure (S0). The system automatically retrieves its 3D pose and body proportion, and performs a rigid morphing on the 3D generic model. The resulting 3D model M1 is projected into 2D (blue lines in S1) and compared with the original sketch (black lines) to evaluate its body fat distribution. M1 is then deformed through fatness morphing into M2, which is projected (green lines in S2) and compared again with the 2D sketch to get the fitting measurements. The final 3D model (M3) is delivered to users, after an automatic surface fitting and beautification process (on M2). Users can incrementally refine their 2D sketches; a similar perception/morphing process is performed to produce the updated 3D model.

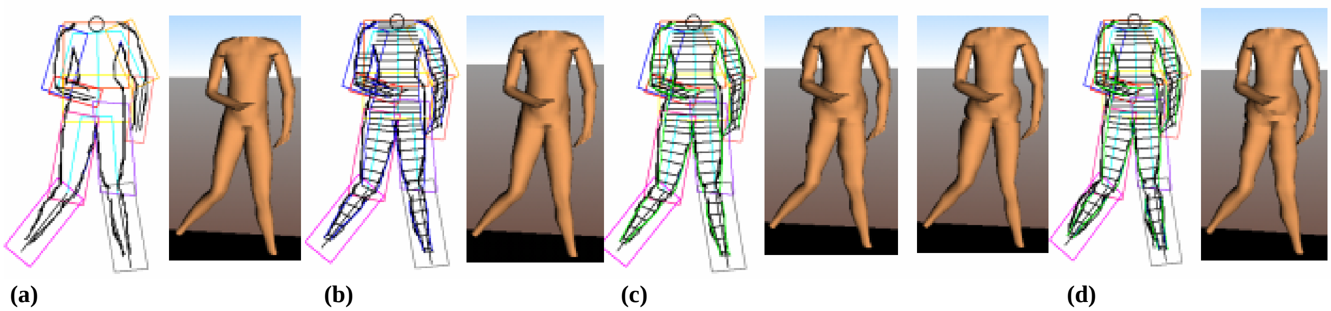

Figure 3. (a) The input 2D freehand sketch and the 3D model after rigid morphing. (b) Graphical comparison to get the fat distribution measurements and the fatness morphed model (c) Graphical comparison to get the surface fitting measurements; the model with and without system auto-beautification (d) Overtracing body contour (right lower torso, and lower legs) to modify an existing 3D surface model.

3.3.2 Transfer 2D raw sketch into 3D plausible body model

As shown in Figure 3(a), freehand figure sketching is essentially rough and imprecise, which contains various "noises" – wiggly/overlapping strokes, missing figure contour, asymmetrical body parts, etc. To turn this sketchy 2D figure into 3D sophisticated mesh model, sketch clean-up needs to be performed. Figure 3 illustrates how a freehand figure sketch undergoes automatic processing and graphical comparison, to be morphed gradually (both "biologically" and geometrically) into a plausible 3D human body model (details in another paper). During this process, an "auto-beautification" option is also offered to regularise an asymmetrical sketch-generated model (see Figure 3(c)). Meanwhile, users can interactively refine the resulting 3D model by over-sketching its 2D figure profiles (see Figure 3(d)). Modifications can be made at any time, and on any key frame sketch, to achieve the updated 3D model. In addition, a post-processing function is also provided for varying an existing figure model, by changing its body proportion.

Beyond a flat drawing medium, it will be ideal to provide users with an interactive and mixed modelling environment, in which they can sketch 2D figure, "pop it up" into a 3D character, and incrementally refine it through suggestive contours [29], shading/shadow, etc, in both 2D and 3D. Having realized the sketch-based figure fast prototyping, the implementation of other features will be our next challenge.

3.3.3 Generate 2D and 3D virtual human animation

Following the "stick figure → fleshing-out → skin mapping" pipeline, a 3D virtual human animation is accomplished by wrapping the sketch-generated skin surface onto a series of posed stick figures, which can be further interpolated via VRML [30], with the associated graphical motion definition. Figure 5(Top) shows the snapshots of the 3D animation specified by Figure 4, which provides an insight of our virtual human sketching interface, and its intuitive graphical tool kits.

While inspiring to "pop-up" 3D virtual beings by freehand "doodling", it is also an amusing experience to animate the 2D sketchy figures, like 2D cartoon storyboarding. This is different from the traditional cel animation, and users do not need to render each key frame, once a single key figure fleshed-out.

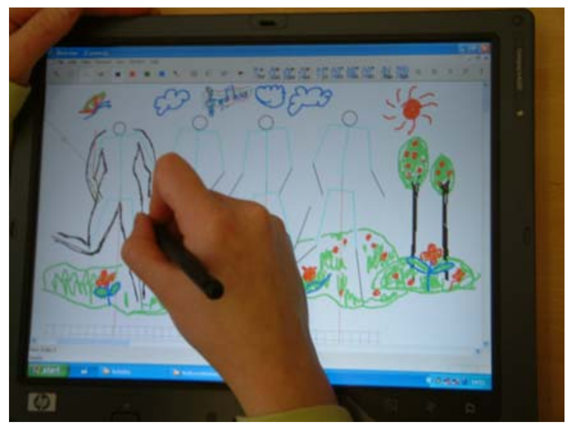

Figure 4. The user is sketching-out a virtual human and its motion on a Tablet PC.

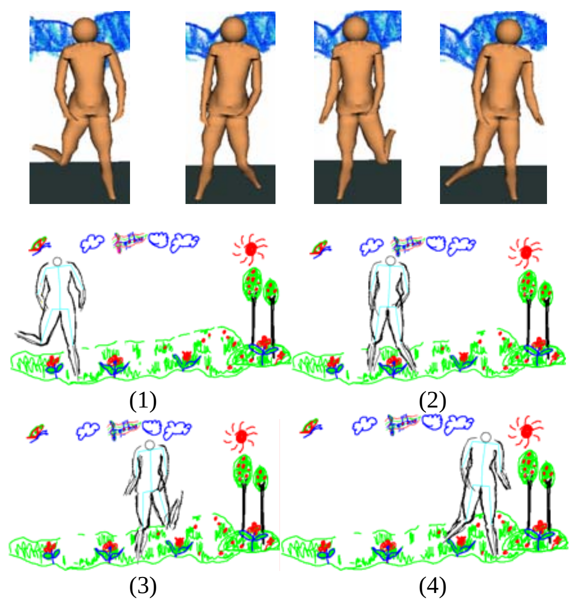

Figure 5. (Top) A sketch-generated 3D dancing character. (Bottom) The 2D NPR animation played on the sketching interface in a doodled countryside view.

Figure 5(Bottom) shows the snapshots of a 2D NPR animation (derived also from the storyboarding on Figure 4) in a doodled countryside view.

4. CREATE AND ANIMATE VIRTUAL HUMAN POPULATION

The techniques for animating computer-generated three-dimensional crowds were greatly refined during the late 1990, starting with feature films like "The Lion King" and "The Hunchback of Notre Dame", and in conjunction with films like "Prince of Egypt", "A Bug's life", to today's "The Lord of the Rings" and "Star Wars" [1]. Regarding the exceptional effect of the crowd animation, in our storyboarding system, we offer a simple sketch-based function for users to animate a population of sketch-generated 3D characters.

In our system, users can either create the assorted virtual humans and their motions by 2D sketching, and store them into the interface-embedded character and motion library; or choose the ones they like from the system provided actor and action lists. Since the 3D motions of some individuals might be similar in a group animation, we offered a motion retargeting function, which can adapt a single action onto multiple characters with various appearances. To specify the character locations on the 3D floor, users can draw simple crosses or circles (see Figure 7(a)) onto its top view plan, to indicate the starting positions (body root XY value) of the crowd individuals. Here, we presume that each character's feet are touching the ground (default as flat) at the beginning of the motion. Users can define the shape of the floor either by selecting from the provided patterns, or by customising some existing ones.

In brief, the procedures for creating a group animation (in our system) are:

1. Create/select a 3D virtual actor.
2. Create/select a 3D motion.
3. Motion targeting to animate the selected character.
4. Draw 2D landmark (cross/circle) to locate the character onto 3D virtual floor.
5. Repeating step 1-4 for each group individual, until the whole animation set-up finished; play to view the group animation result in VRML.

Figure 6 below shows the sketches and a range of variational 3D human bodies, which were created by various users in our user test (details in Section 6). Figure 7(a) illustrates the sketch-based character allocation. Figure 7(b) shows the group animation result, in which a population of virtual humans from users and some previously illustrated figures are playing Chinese Kungfu together in 3D virtual world with music (see also the attached video clips). Here, a single Kungfu motion was applied onto each of the group individuals. In Figure 9, a crowd animation with intercommunication and variational actions is presented.

5. 2D STORYBOARDING FOR THE 3D MULTIPLE CHARACTER INTERCOMMUNICATION

In 2D storyboarding, the intercommunication among actors/actresses is usually vital to transfer the drama and emotion of the story and characters. Meanwhile, some psychological researchers have concluded that more than 65 percent of the information exchanged during a face-to-face interaction is expressed through nonverbal means [31]. In our storyboarding interface, users can draw multiple characters in each keyframe to show the flow of interactions, like defining the visual camera shots (see Figure 8(Top)). To draft the character motions, users can sketch either fully rendered figures, or only simple stick figures to illustrate prompt ideas. Meanwhile, users can also annotate their drawings with script dialogue, or some other notes/symbols to assist the storytelling. The system can reconstruct the 3D motion for each character sequentially from the 2D storyboards. For the motion path editing, users can either sketch-out the motion curves separately for each individual, or specify it for just a single actor. The system can automatically estimate the associated motion information for the other characters through analysing their relative interface locations (depth relationships not included). Similarly, users can sketch-out the timing for each character, or define a single one and apply it onto the other story actors. After the 2D storyboarding and the 3D reconstruction, the final 3D animation with interactive characters can be displayed via VRML after a single user click. Figure 8(top) shows the 2D storyboards of two characters Kungfu fighting with each other, with some associated annotations and motion curves. Figure 8(bottom) presents the snapshots of the synthesised 3D fighting motion. Meanwhile, users can also create the group animation of interactive characters through the same means as described in Section 4. The default local origin for each character set is the body root of the leftmost character on the corresponding first keyframe sketch (see Figure 8(top)). Figure 9 shows an interesting animation of a crowd of virtual humans and even stick figures fighting with each other in 3D virtual world. Among them, some characteristic figure actions (appeared in Figure 1 and 5) could be spotted to show the individualities among the collective behaviours.

6. IMPLEMENTATION AND USER EXPERIENCES

Our prototype modelling and animation system is implemented by Microsoft Visual C++, MATLAB, and VRML. This system has been tested on a variety of input devices: electric whiteboard, Tablet PC, as well as a standard mouse.

On the completion of our storyboarding system, we conducted a formal user evaluation to assess its usability and functionalities with various users (including artists, animator, undergraduate/postgraduate students, and a 12-year-old boy), through performance tests, sketching observation, and user interviews. After a short tutorial, users rapidly learned the storyboarding process, and began sketching-out their own virtual humans and animations (on Tablet PC) within minutes. In general, the overall average time for creating a complete stick figure animation and a complete full figure animation (both containing 3 keyframes) is 6.27 minutes and 6.75 minutes respectively. It is in remarkable contrast with the commercial packages, which requires usually dozens of minutes and several hours respectively for an animator, to create the similar articulated and full character animation from scratch.

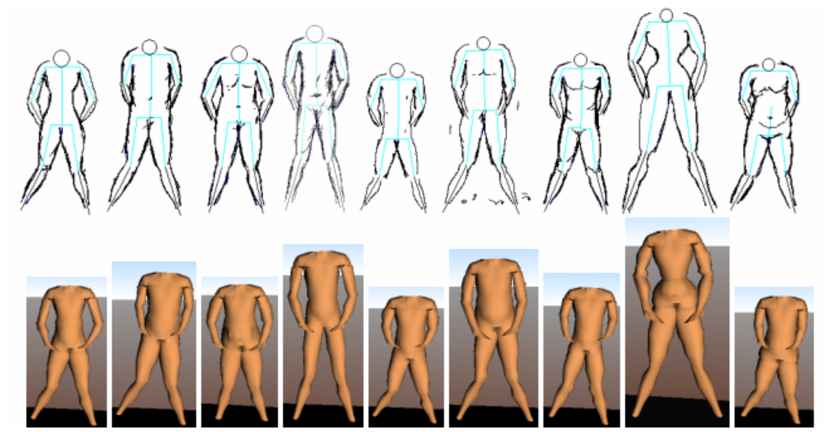

Figure 6. A variety of 3D virtual humans and the original drawings by different users: artist (S3), design student (S4), animator (S6, S7), graduate students (S1, S2, S5, S9), and a child (S8). The inner contours on some sketches (S3, S4, S6, S7, S9) are added after the 3D model generation, which shows user's intention to depict the detailed surface shape through more rendering forms.

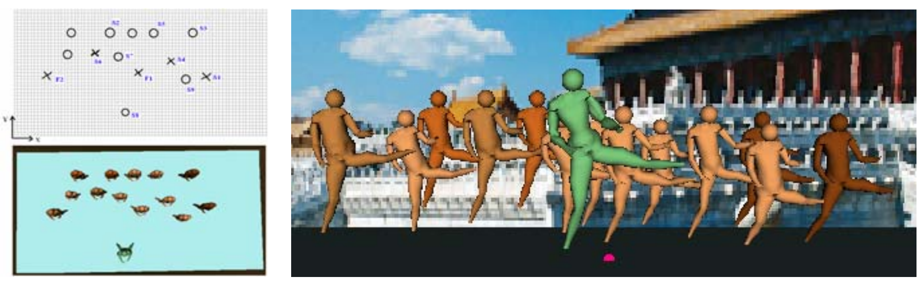

Figure 7. (a) 2D top view plan with the denoted character locations (S1-S9 and F1-F2 are the indices of the characters, which appeared in Figure 6 and Figure 1,5), and the corresponding 3D result. (b) Kungfu group animation with music and background (the pink ball on the floor is a touch sensor to trigger the music).

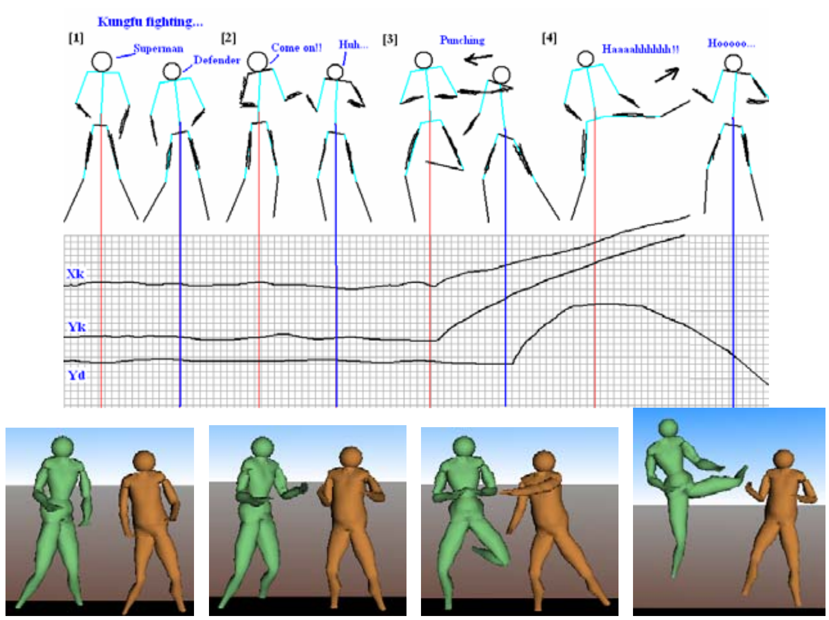

Figure 8. (Top) The Kungfu fighting storyboards with the associated annotations and motion curves (Xk and Yk are the X and Y trajectory curves for the kicker. Yd is the Y curve for the defender, who's path x value can be automatically estimated. The motion timing was act-out by the curve drawing speed.) (Bottom) Two sketch-generated 3D characters are fighting with each other.

Moreover, this modelling/animating by sketching approach is proved by users to be easy to learn and use, and entertaining to play with. Figure 6 shows the sketches and the variational human bodies created by users during the test, which have been integrated into two group animations, shown in Figure 7 and 9.

7. CONCLUSIONS AND FUTURE WORK

In this paper, we have presented a fast and novel storyboarding interface for sketching-out 3D virtual humans, 2D/3D animations, and character intercommunication. Human modelling and animation is a recognisable challenge and a labour-intensive task, which has been, until now, confined to the domain of professionals. This research draws on the people's existing drawing skills and the intuitiveness of 2D storyboarding as a design tool, to enable ordinary users to create and animate their own living characters, with ease and fun. Our main contributions in this work are: 1) we devised an intuitive "stick figure→fleshing-out→skin mapping" graphical animation pipeline, which realises the whole process of key framing, 3D pose reconstruction, virtual human modelling, motion path/timing control, and the final animation synthesis by almost pure 2D sketching; 2) we investigated an easy and fast approach, which enables the sketch-based crowd animation and the storyboarding for the 3D multiple character intercommunication. On the success of the current system, we envisage its applications in human modelling and animation, CG animation/film making, cartoon storyboarding, interactive game (on Internet, home PC, or mobile devices), virtual reality, education, etc.

The animation system presented here is not meant to be a substitute for the array of professional animation tools and techniques that are commonly used in film and game production. Instead, our storyboarding system provides an alternate and more accessible means for ordinary users, to create the simple and entertaining animations in various forms. Meanwhile, this system can be also utilised as a fast prototyping machine, from which the sketch-generated 3D character models and animations can be created and imported into commercial tools, to be refined by their powerful function kits.

In the future, we are going to extend our system to allow the generation of a full range of population, including females, children, elders, etc. We will realise an interactive 2D and 3D drawing environment, and adopt more rendering forms (i.e. suggestive contours, shading/shadow) to depict subtle surface features. We will investigate the appropriate means to detect and avoid the collisions in a crowd animation. Meanwhile, it is also our future work to further enhance the system functionalities, through enabling the storyboarding of character expressions, and the writing-based phonic dialogue creation.

8. REFERENCES

[1] Isaac, V.K. *The art of 3D computer animation and effects*. 3rd edition, John Wiley & Sons, Inc., Hoboken, New Jersey, 2004.

[2] Fox, B. *3ds max 6 Animation: CG Filmmaking from Concept to Completion*. McGraw-Hill Osborne, California, U.S.A.,2004.

[3] Hoshino, J., and Hoshino, Y.: Intelligent storyboard for prototyping animation. In *Proc. IEEE Int. Conf. On Multimedia and Expo* (2001), Conference CD-ROM FAI.03.

[4] Wilhelms, J., Van Gelder, A. Anatomically based modeling. In *Proc. SIGGRAPH '97* (1997), 173-180.

[5] Magnenat-Thalmann, N., and Thalmann, D. The direction of synthetic actors in the film Rendez-vous à Montréal. *IEEE Computer Graphics and Applications* 7,12 (1987).

[6] Hilton, A., Beresford, D., Gentils, T., Smith, R., and Sun, W. Virtual people: capturing human models to populate virtual worlds. In Proc. *Computer Animation*, IEEE Press (1999), 174-185.

[7] Allen, B., Curless, B., and Popovis Z. The space of all body shapes: reconstruction and parameterization from range scans. *In Proc. SIGGRAPH 2003* (2003), 587-594.

[8] Anguelov, D., Srinivasan, P., Koller, D., Thrun, S., and Rodgers, J. SCAPE: Shape Completion and Animation of People. *Proc. SIGGRAPH 05* (2005), 408-416.

[9] Grochow, K., Martin, S. L., Hertzmann, A., and Popovic, Z. Style-based inverse kinematics. *ACM Transactions on Graphics (TOG) 23, 3 (2004), 522-531.*

[10] Weber, J. Run-time skin deformation. Intel Architecture Labs, http://www.intel.com/ial/3dsoftware/index.htm (2006).

[11] Ekman, P., and Friesen, W. *Facial action coding system*. Consulting Psychologists Press, Palo Alto, 1978.

[12] Bruderlin, A., and Calvert, T.W. Goal directed, dynamic animation of human walking, *Proc. SIGGRAPH '89, Computer Graphics* 23, 3 (1989), 233-242.

[13] Turner, R., and Gobbetti, E. Interactive construction and animation of layered elastically deformable characters. *Computer Graphics Forum* 17, 2 (1998), 135-152.

[14] Fua, P. Human modeling from video sequence. *Geometric Info Magazine* 13, 7 (1999), 63-65.

[15] Igarashi, T., Matsuoka, S., and Tanaka, H. Teddy: a sketching interface for 3D freeform design. In *Proc. SIGGRAPH '99* (1999), 409-416.

[16] Alexe, A., Gaildrat, V., and Barthe, L. Modelling from sketches using spherical implicit functions, *Proc. 3rd international conference on Computer graphics, virtual reality, visualisation and interaction in Africa* (2004) 25-34.

[17] Karpenko, O., Hughes, J. F., and Raskar, R. Free-form sketching with variational implicit surfaces. *Proc. Eurographics 2002* 21, 3 (2002).

[18] Wang, C.C.L., Yuen, M.M.F. Freeform extrusion by sketched input. *Computers and Graphics* (2003), 255-263.

[19] Davis, J., Agrawala, M., Chuang, E., Popovi , Z., and Salesin, D. A sketching interface for articulated figure animation. In *Proc. Eurographics / SIGGRAPH Symposium on Computer Animation* (2003), 320-328.

[20] Mao, C., Qin, S.F., and Wright, D.K. A sketch-based gesture interface for rough 3D stick figure animation, *Proc. of Eurographics Workshop on Sketch Based Interfaces and Modeling* (2005), 175-183.

[21] Thorne, M., Burke, D., and van de, Panne, M. Motion doodles: An interface for sketching character animation. *ACM Transactions on Graphics 23*, 3 (2004), 424- 431.

[22] Bregler, C., Loeb, L., Chuang, E., and Deshpande, H. Turing to the masters: motion capturing cartoons. *ACM Transaction on Graphics* 21,3 (2002), 399-407.

[23] Li, Y., Gleicher, M., Xu, Y-Q, and Shum, H. Stylizing motion with drawings. *Proceedings of 2003 Symposium on Computer* Animation, 2003.

[24] Chaudhuri, P., Kalra, P., and Banerjee, S. A system for view-dependent animation. *Eurographics 2004* 23, 3 (2004).

[25] Lipson, H., and Shpitalni, M. Correlation-based reconstruction of a 3D object from a single freehand sketch, *In Proc. AAAI Spring Symposium Series - Sketch Understanding*, 2002.

[26] Tiner R. *Figure drawing without a model*. David & Charles plc, Glasgow, 1992.

[27] Li, W. Figure drawing: Basic pose and construction. FARP,http://elfwood.lysator.liu.se/farp/figure/williamlibodyconstruction.html (2006).

[28] National Library of Medicine. The Virtual Human Project, http://www.nlm.nih.gov/research/visible/visible_human.html (2006).

[29] DeCarlo, D., Finkelstein, A., Rusinkiewics, S., and Santella, A. Suggestive contours for conveying shape. *ACM Transaction on Graphics* 22, 3 (2003), 848-855.

[30] Ames, A. L., Nadeau, D. R., and Moreland**,** J. L. *VRML 2.0 Sourcebook.* 2nd edition, John Wiley & Sons Inc., 1997.

[31] Argyle, M., *Bodily communication*. Methuen & Co., New York, 19

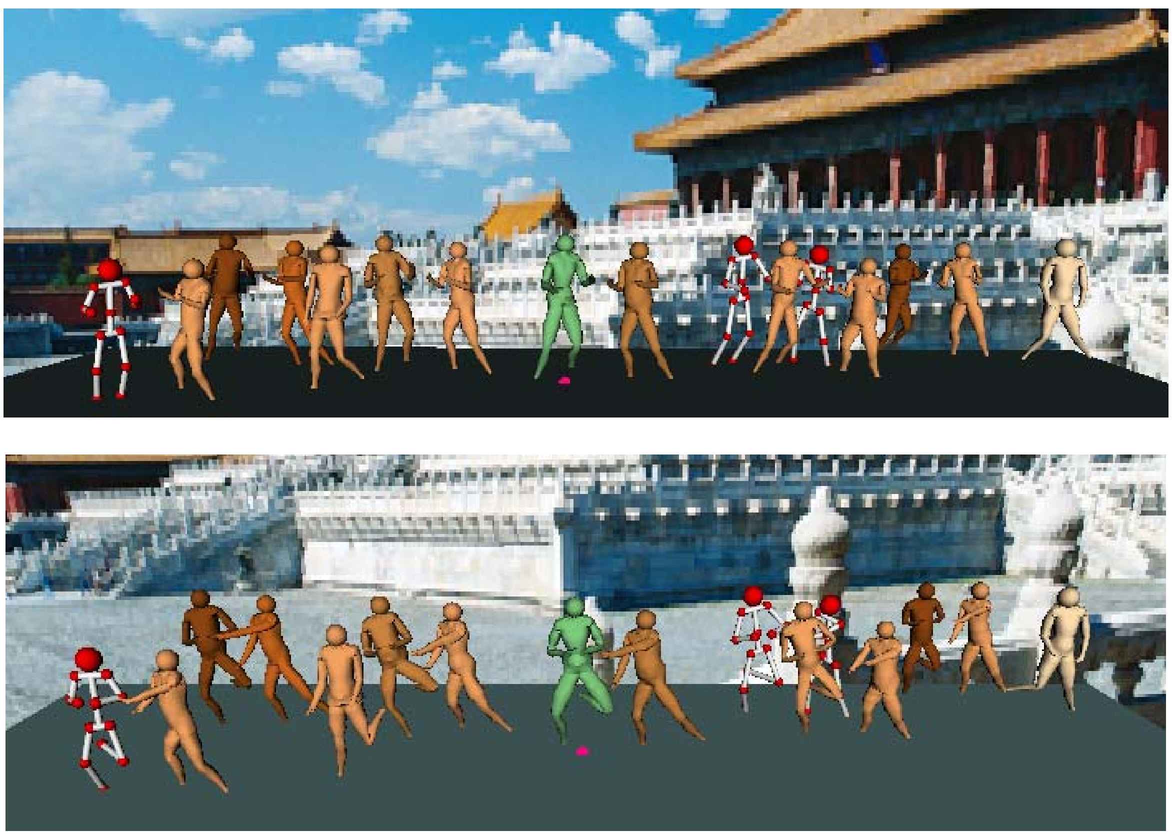

Figure 9. A crowd of variational virtual humans and stick figures are fighting with each other in 3D virtual world. Two of them (the 5th from the left, and the right most figures) are acting differently, which shows the individualities among the collective behaviors.