Automated finger spelling by highly realistic 3D animation

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Abstract
We present the design of a new 3D animation tool for self-teaching (signing and reading) finger spelling—the first basic component in learning any sign language. We have designed a highly realistic hand with natural animation of the finger motions. Smoothness of motion (in real time) is achieved via programmable blending of animation segments. The hand is utilised by a programme that automatically converts text to finger spelling with controllable playback speed and playback views. The programme can be operated in two modes for two basic applications: learning to read (finger spelling) and learning to sign. For both modes, multi-sided views are provided. In addition, for the signing mode, a mirror view is provided for the common technique of using a mirror for feedback in practising finger spelling. An additional view revealing the joint structure of the hand allows the signer to practise the subjective view without having to guess the position of the fingers. This is the first example of highly realistic 3D animation that can be used practically to teach a basic aspect of sign language. The method is applicable more generally to sign language, and this finger-spelling application should be regarded as a first step toward the extension of highly realistic 3D animation to sign language in general.

Importance and difficulty of learning sign languages
Two of the most critical problems in helping the deaf community achieve high standards of education are (1) early acquisition of language by deaf children, and (2) early acquisition of the ability to read text in English. In the first case the risk is delayed intellectual maturation since language is basic to intellectual development (if not developed early, language skills are never acquired). In the second case the risk is inability to access higher education. In fact, the majority of deaf children of high school graduation age read English only at the fourth grade level (Gallaudet Research Institute, 1996).
In order to attack these two basic problems of the education of the deaf, different linguistic schools have been debating the importance of teaching American Sign Language (ASL), or some other type of sign language based on English syntax. ASL is the native language of the deaf community, and it is the language transmitted naturally in the deaf culture. The grammar and syntax differ markedly from English such that ASL can be regarded as a foreign language to speakers of English. On the other hand, the types of sign languages based on English retain the syntax of English and can be regarded not as foreign languages but as different ways of coding the English language. The coding makes use of signs taken from the vocabulary of ASL with few adaptations. Among these types of sign languages three are most notable: Signed English (SE), Signed Exact English (SEE) and Pidgin Signed English (PSE) (Kyle and Woll, 1985; Bornstein, 1982).

Both SE and SEE use ASL signs, initialisation of signs (i.e., the use of finger-spelled letters for the first letter of an English word expressing a similar concept), markers of inflection, and signs for articles and infinitives. In SEE all the words are signed. PSE uses the signs of ASL and also as well as its facial expressions and body language, in English word order. It does not attempt to code English word for word. PSE is much easier for hearing people to acquire and as such is widely used.

ASL is the choice for early acquisition of language by deaf children (Sacks, 2000) raised in the deaf community. On the other hand, only 3% of deaf children are born of two deaf parents. Thus, in the overwhelming majority of cases, it is not ASL that is most commonly used as a way of communicating with the deaf child. Sign languages based on English syntax, which retain the grammar and syntax of English, are much more easily acquired (especially PSE) by hearing parents. These languages (especially SEE) are also the choice (Gallaudet University, http://www.gallaudet.edu) for the transition to reading text English (and generally acquiring English as a second language), thereby facilitating access to higher education. SEE, SE and PSE are also most effective when used in conjunction with speech, which is important for persons with some degree of residual hearing.

Regardless of which sign language is chosen, there are significant, intrinsic difficulties in acquiring proficiency in any sign language. In fact, the difficulty in helping the deaf community in the two areas mentioned above stems from various reasons but lies primarily in the difficulty of acquiring a sign language by hearing adults (e.g., parents of deaf children) and in the difficulty of practising SE/SEE to make the transition into text English (hence learning to read proficiently) by the deaf person (see e.g., Odyssey, http://clerccenter.gallaudet.edu/Odyssey/index.html).

Particularly remarkable is the disadvantage of the Deaf, both the deaf child acquiring language and the deaf student trying to learn English via SE/SEE, regarding the amount of media content that is accessible. Whereas hearing children and adults are immersed in a plethora of engaging media material in which images are associated with language, for the Deaf media are dissociated from language since neither ASL nor SE are simul-
taneously present with images (with some obvious exceptions—interpreters broadcasting on TV generally use SE displayed in a corner of the screen during broadcasting). Closed captioning, incidentally, works only for those who have already acquired English text reading proficiency but, as mentioned, this is not the norm.

In addition to this media ‘deprivation’, there are intrinsic difficulties in solving the two problems emphasised at the outset. A major obstacle in sign language acquisition is the near impossibility of self-teaching. Whereas learning to sign and to ‘read’ the signing of users of ASL and SEE is difficult, as is learning any other foreign language, sign languages are unique in that there is no convenient way of self-teaching.

Regular foreign languages can be self-taught by using tape recorders and microphones for correct feedback. Feedback in sign language cannot be obtained from studying textbooks nor from video or CD. The only feedback is generally the mirror, which is a misleading tool since it provides incorrect feedback. Actually practising in front of a mirror is an example of the fact that most people who attempt to self-teach sign language end up spending time practising errors, which is more detrimental than not practising at all (Schein, 1984).

This paper focuses on the problem of self-teaching sign languages, beginning with the most basic first step in learning any sign language, that is, finger spelling. Learning finger spelling (dactylology) is a prerequisite to learning to sign in ASL, SE, SEE or PSE. Finger spelling is essential for four reasons. It is used in combination with sign language for (1) names of people, (2) names of places, (3) words for which there are no signs and (4) as a substitute when the word has not yet been learned. It is generally learned at the beginning of any course in any sign language also because the hand shapes formed in finger spelling provide the basic hand shapes for most signs (see eg, Flodin, 1994).

In spite of its importance and its apparent simplicity, high proficiency in finger spelling is not easy to acquire, mainly for the reasons outlined above concerning sign language acquisition on the whole. In this paper an effective tool for self-teaching finger spelling is presented along with an introduction to a methodology for developing tools for self-teaching sign languages in general. This paper should be regarded as a first step of a comprehensive programme to apply this methodology to the solution of the two basic problems stated at the beginning of this section.

**Plan and overview**

The paper focuses on the design of a new 3D animation tool for self-teaching (signing and reading) finger spelling. Attempts at using computerised animation to assist with learning sign language began as early as the late 1970s (Withrow, 1978a; Withrow, 1978b), but progress has been slow. In the 1980s and 1990s the focus shifted to video (Newell, 1983; Fogel, 1990; see also http://commtechlab.msu.edu/products/pcom/index.html) and more recently to CD-ROMs (see eg, the list at http://clerccenter.gallaudet.edu/InfoToGo/545.html).
Currently, the technology of computerised animation is making great progress rapidly. In this spirit we have concentrated our method on the use of advanced 3D computerised animation. In the next section we present the design of a realistic hand with realistic/natural animation of the finger motions in finger spelling. The hand is of ideal size for practising finger spelling. The few animation programmes currently available present the hand in two dimensions (see http://where.com/scott.net/asl/) and/or in small size (see http://www.bilagaana.com/asl/asl.html, http://www.signingavatar.com).

The lowest-resolution computer monitor displays $640 \times 480$ pixels. Because of the interlacing, the effective resolution of a TV screen is $512 \times 400$ pixels (http://entertainment.howstuffworks.com/dtv2.htm). The appearance of our hand on a standard computer display (19” monitor, resolution of $640 \times 480$) is of approximately the same size as the hand observed while practising finger spelling using a videotape on a 19” TV set.

Realism helps in identifying the shape and motion of the hand, which normally can be confusing unless the hand is realistic. To follow 23 degrees of freedom (the human hand has this many degrees of freedom) is not easy to the eye. This is especially true for large audiences since in this case the hand is seen at a distance. With finger spelling produced by 3D computerised animation, it is possible to design large-sized displays (such as those used in a stadium) which can project the finger-spelled hand in large scale. In this case a realistic, natural- looking hand is essential.

In general, the type of image (eg, abstract vs realistic) is expected to be a significant factor in cognition and learning. However, research in this area, although growing in importance, has yet to provide definite answers. A notable example is research done on the influence of types of images in children books (see eg, Andrews et al, 2002). There have not yet been any conclusive results on the effects on children of the various types of illustrations. Intuitively, and also according to some motivation theories (Glenberg and Langston, 1992), it could be assumed that illustrations may make a book more attractive and thus better involve a child. In fact, results of experiments on third graders’ reading comprehension of illustrated books (Andrews et al, 2002) supports this view. More importantly, in a fourfold choice among bright-realistic, bright-abstract, sombre-realistic and sombre-abstract types of images, children performed best with bright-realistic images. Thus, our approach for deaf children is supported by evidence that appears to apply to a wider range of cognitive and learning situations.

The question may be raised as to whether or not the addition of a ‘lean’ (sombre-abstract) version of an image to the bright-realistic one would further enhance the appeal and cognition of the bright-realistic image. If this were the case, it would be worthwhile to consider the option of adding (eg, by morphing or juxtaposition) the abstract version to the realistic version of the image. In this paper we do not investigate this aspect, but we present a case in which the ‘skeleton’ is superimposed on the realistic rendition of the hand. Further research on these ‘double’ types of images will be pursued elsewhere.
Smoothness of motion may not appear to be significant at high rates of finger spelling. And since high speed is needed for fast communication, it would seem that smooth animated motion is not necessary. Yet smoothness of motion is important for readability of the sign. In fact, generally it is better for the learner to first develop a smoothness of motion between letters than speed (Butterworth and Flodin, 1989).

Developing a realistic hand is also significant independently of applications requiring real-time animation. For example, closed captioning with finger spelling can be produced off-line. Similarly, automated production of finger-spelled books is done off-line. For the latter purpose, the realism of the hand is particularly suitable since it enhances readability while its effectiveness is not hampered by production of signs at speeds lower than the natural rate of finger spelling.

Later, we present the user interface that allows for complete control of the finger-spelled word to be signed (text-to-finger spelling conversion). Programming is done in Maya Embedded Language (MEL) (http://www.alias.com). This choice was made by considering that MEL, while achieving approximately one-tenth of the speed obtainable by programming the animation in C++, considerably reduced the development time. It is actually the Maya real-time player that limits the speed—the ‘physical’ limitation being determined primarily by the number of polygons used in the model. As discussed later, when using the low-polygon version of our hand speeds of up to twice the natural rate (30 frames/second) are easily achieved.

The speed of the animation is important in practising and learning finger spelling. For the beginner observing people finger spelling at natural speed, the signs usually cannot be resolved, with the fingers appearing as a moving blur. The situation is entirely analogous to the learning of a foreign language. The beginner usually finds it impossible to resolve the words spoken at a natural rate of speech. Consequently, she needs to practise with language spoken at a lower rate until, by gradually increasing the rate of speech, she becomes able to resolve words spoken at a natural rate. For this purpose, videotapes are of no help whereas computer-based language programmes (see eg. http://www.transparent.com) provide a convenient way of controlling rate of speech and so that learners can gradually become accustomed to the natural flow of sounds.

Superficially, it may appear that the situation is different for sign language since videotape movements can be slowed down without distortion (contrary to what happens to sound when tape speed is slowed); in practice, however, speed reduction is for a few fixed values and is awkward to operate. Only DVDs and animation can provide this control. However, DVDs are limited in the range of drills that can be offered to the student, whereas computer-driven animation can provide an endless source of different drill exercises. The speed control in our programme ranges from 1 to 60 frames per second so that finger spelling can be practised at very low speeds up to twice the natural rate.
We remark that this factor—the ability to finger spell at a rate higher than natural—offers the unique opportunity of exploring the human ability to resolve (read) finger spelling at speeds higher than the natural rate. Although this ability could have been measured using videotapes run at speeds higher than normal, the investigation, while interesting scientifically, would have been devoid of applications since no device is available for signing in real-time arbitrary text.

Furthermore, since 3D animation can convert text to natural-looking finger spelling at speeds higher than humanly possible, new devices can be explored. A natural signer cannot achieve a speed higher than about 50 words per minute. But a natural reader might be capable of reading signing at a much higher speed. This appears very plausible by analogy with typed text. The text can be input only at a maximum of approximately 220 words per minute (with special computer-assisted devices), but text can be read at speeds higher than 500 words per minute. Thus, signalling to the deaf may be done by 3D animation text-sign computer-based converters more efficiently than by human beings. This would be viable primarily for SE and SEE (rather than ASL) since these are a coding of English rather than a translation. As, neither SE nor SEE presents the major linguistic problems of translating into a foreign language.

Another important characteristic of the dynamics of finger spelling besides the overall speed, is the flow of the motion, that is, the differential speed of the various letters presented. First, there is the obvious need to pause between words, second, the need to pause longer on some letters, especially the last one for emphasis. Third, it is desirable to group letters in ‘syllables’ and hence to speed up the presentation of the letters forming a syllable in comparison to the rate of presentations of the syllables themselves. Fourth, while presenting doubles is generally achieved by a slight translation of the hand to the right, in the case of letters represented by ‘closed’ fingers (eg ‘K’ or ‘S’) it is customary to make a quick, weak transition between the same letter. This is again an example of the need to tune differentially the speed of finger spelling. In this work we have taken such problems into account by allowing for the programming of differential speeds for all of the four factors listed above.

Another point worth noting about automated finger spelling is related to the cut-and-paste method used in some applications (see eg, http://www.where.com/scott.net/asl/). The words produced with this method are not realistic since they do not represent what actually is being signed. In actual signing the transitions between letters cannot be eliminated from sight, thus the observer must learn to see the letters formed via transitions from one letter to another. These transitions are skipped in the cut-and-paste method and, incidentally, are never shown in textbook representation of finger-spelling signs. The animation of the motion from one letter to the next is an essential learning element that is not provided by the cut-and-paste method.

Different views of the fingers while finger spelling are necessary for effective practice and learning. This is evident from reviewing currently available commercial videotapes
designed to teach finger spelling (see eg, http://clerccenter.gallaudet.edu/InfoToGo/545.html) and more specifically the video Fingerspelling Practice (SMI, 1991). It is especially important to observe the so-called subjective view, that is, the view from the signer perspective. This view, although hindering much of the fingers, permits the practising signer to observe her own hand moving in the correct fashion.

Later, we discuss the two modes of operation of the user interface. Our interface can provide full rotation of the hand view; however, for learning purposes, it is convenient to have fixed basic views to which the student can return for reference and comparisons in different drills. For this reason, we have divided the set views into two groups according to the mode of learning: the reading mode and the signing mode.

In the reading mode, the views available are front, top-front and two side views. In order to acquire proficiency in reading finger spelling, it is important to be able to observe the finger spelling as signed by the communicating person. Accordingly, in this mode four views are available. The front and two side views are those generally observed in conversation. The fourth view included allows close examination of the relationships between fingers and helps resolve ambiguities.

In the signing mode, the available views are mirror, back, ‘transparent’ back and top-back. In order to acquire proficiency in signing finger spelling, it is important to be able to observe one’s own hand in the processes of producing the correct signs. This observation, as noted previously, is critical for guidance in forming the letters and for feedback about errors. However, for most letters the fingers remain hidden. One solution is to present the subjective (back) view together with the mirror view.

In this way it is possible to practise by using a mirror in conjunction with the computer. As the letters are formed and observed from the subjective view, it is possible to observe if the hidden fingers are positioned correctly by comparing the view in the actual mirror with the mirror view produced by the computer.

The fourth view presented in the signing mode is the top-back view which, although not easily observable in practice, helps in understanding the relationships among the fingers as seen from the signer point of view.

A third view is discussed later. This is a ‘transparent’ view of the hand showing the bone joints of the fingers so that the subjective view becomes an effective way of practising signing since the complete motion of the fingers becomes visible.

A realistic hand for natural animation

*Initial challenges*

Modelling and animating a realistic hand presented three main challenges:
1. In order to achieve a realistic appearance, the hand needs to be modelled as a continuous skin with special attention to details such as knuckles, tendons, skin creasing and folding, webbing and fingernails.

2. In order to clearly represent the 26 hand shapes of the manual alphabet, the hand needs to be flexible enough to move in a realistic manner.

3. In order to maintain a realistic appearance during animation, the hand needs to deform with organic realism.

In answer to these three challenges we have proceeded as follows:

1. The hand that we present was modelled as a continuous polygonal mesh. Knuckles and tendons were created using sculpting tools; detail was added in the areas of main creases and folds (Kundert-Gibbs and Lee, 2001). The fingernails were modelled out of primitive spheres and attached to the ends of the fingers. The use of these modelling techniques enabled us to achieve a degree of realism so far not present in hands for text-to-finger spelling conversion using 3D animation. In the first and, so far, only commercial product capable of producing text-to-finger spelling conversion using 3D animation, the hand is partially-segmented with a detached thumb composed of three segments (see http://www.signingavatar.com).

2. Our hand makes use of a skeletal deformation system (in this type of system the skeleton is what is actually animated). The hierarchical structure of the skeleton, together with the location and number of joints, closely resembles the skeletal structure of a real hand and arm, allowing extremely realistic motion. This is particularly evident in the case of the letter J, which requires a semicircular motion (see Figure 1). The arm and hand are animated using a sophisticated skeleton structure that makes use of both Forward and Inverse Kinematics. An extra joint was added between the elbow and the wrist. This extra joint allows the natural twisting of the forearm that occurs when the wrist is rotated (Graft et al., 2002). With this set-up it was possible to produce the realistic circular motion of the hand during the animation of the J and Z hand shapes. Without using this method the motion to produce the J and Z hand shapes would result in the motion of the whole arm (http://www.signingavatar.com).

3. The skeleton of our hand was bound to the polygonal mesh using a rigid bind. Membership sets were adjusted to create realistic deformation effects (ie, creasing and webbing, which are presented here for the first time in the context of finger spelling). Examples of the modelled hand are shown in Figures 2 and 3.

Secondary challenges

After modelling the hand for realistic, natural motion, preparing the hand for real-time interaction presented two further challenges:

1. Since the total number of polygons directly affects the speed at which a computer can process a model (O’Rourke, 1999), the polygon count of the hand needs to be kept as low as possible while also retaining the realistic appearance of the original model. This is the classic problem of, for example, video game character design.

2. In order to speed up the text-to-finger spelling conversion programme and the development time, the number of transformation parameters involved in the animation of each hand shape should be kept to a minimum.

We have answered these challenges as follows:

1. We used Maya 4.0 Real-time Player and an average computer system with the following specifications: DCS Pentium III Dual processor 933Mhz, 256 Meg PC-133 Dimm Memory, nVidia Quadro 2 graphics card. We varied the number of polygons in the hand for six different values. For each value we measured the maximum speed of playback for three letters (we stopped at three since the measured speed was essentially independent of the letter) and obtained an average value which is plotted versus the number of polygons, as shown in Figure 4. From the data we could estimate the number of polygons necessary to achieve a desired playback speed.

On the basis of these data, we constructed a ‘low’ polygon hand with 679 polygons. Though its appearance is blockier than the original hand, the low-polygon hand was able to retain the realistic shape and main details of the original high-polygon hand as apparent from Figures 5 and 6.
2. Fifty-one transformation parameters are involved in the animation of each hand shape (three rotation parameters for each of the three joints of the fingers, $3 \times 3 \times 5 = 45$; three rotation parameters for the wrist and three translation parameters for the Inverse Kinematics handle that controls the motion of the arm). Each one of the 51 parameters needs to be assigned a certain value in order to represent a particular hand shape.

With the use of reactive animation we were able to represent each hand shape by assigning a single parameter value. We defined a main control with 26 parameters (one parameter per hand shape), each one with a range value of 0 to 5. With a value of 0 the hand appears in a neutral position (see Figure 7), and with a value of 5 the hand assumes the pose corresponding to the hand shape.
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Figure 3: Examples of hand realism in forming the finger-spelling alphabet

Figure 4: Maximum speed of letter formation as a function of the number of polygons forming the hand model

The user interface for this project is based on Maya user interface capabilities, and it is intended as an experimental tool, not as a commercial product. It consists of a floating, resizable window from which text can be entered for automatic conversion to finger spelling. The window also includes two sliders for continuous control of speed and orientation of the hand. There are four buttons for convenient setting of the hand in one of four basic orientations. Two additional buttons for special top views and two checkboxes also for the special views are discussed below. The layout of the window is shown in Figure 7.

**Text-to-finger spelling conversion**

The user interface for this project is based on Maya user interface capabilities, and it is intended as an experimental tool, not as a commercial product. It consists of a floating, resizable window from which text can be entered for automatic conversion to finger spelling. The window also includes two sliders for continuous control of speed and orientation of the hand. There are four buttons for convenient setting of the hand in one of four basic orientations. Two additional buttons for special top views and two checkboxes also for the special views are discussed below. The layout of the window is shown in Figure 7.
For text input the 26 upper-case letters can be used. The underscore character ‘_’ is used to introduce pauses. If a single letter is the text input, then the hand moves from the neutral position to form the letter and returns to the neutral position. If the input consists of two distinct letters, the first letter is formed from the initial position and, after reaching the finger-spelling configuration, begins to return to the neutral position but does not complete the process, the motion being merged with the beginning motion of the next letter.

The key point for this type of smooth transition is to avoid the finger-crossing effect. This consists of the unnatural appearance of a hand in which the fingers merge one into another or in which fingers cross the palm. To avoid this spurious effect which is common in combining motion, we have devised a blending algorithm, using the trax editor, for combining clips of animation that resolve the problem for all possible 650 combinations of two pairs of distinct letters.

For pairs of identical letters (ie, doubles), if the letters are represented by ‘open’ fingers configurations, such as ‘L’, the problem is solved by following the finger-spelling convention of slightly translating the wrist to the right while keeping the same finger-spelling letter shape. The problem of finger crossing effect does not arise. For doubles of ‘closed’ fingers configurations, such as ‘S’, the programme, following the finger spellers’
custom, makes a briefer transition between the letters. To our knowledge this feature is unique to our programme.

The underscore character allows for return to the neutral position. Normally one underscore would be inserted to separate different words. Thus, the output is not restricted to single words but allows for the representation of sentences. Similarly, the finger-spelled letters can be grouped into syllables. This is a recommended practice in the learning process. However, this feature is not currently available in commercial products. Multiple underscore characters increase the ‘resting’ time between words or letters in proportion to the number of underscore characters.

Figure 8 presents an animation of the finger spelling of the sentence ‘Nikko LLP Shizuoka Japan’ which could be the name and address of a business. Thus, this sentence would be entirely finger spelled in ASL or SE/SEE. In the programme the text input is ‘NIKKO_LLP_SHIZUOKA_JAPAN’. This example illustrates various features of the programme: (1) animation of the special letters J and Z, which require special motion, (2) animation of the closed doubles ‘KK’, (3) animation of the open doubles ‘LL’, (4) the pauses between words, and (5) the natural speed of execution.

**Two modes of operation**
The window interface allows for different views of the hand during finger spelling, which is necessary since a single view generally occludes some fingers and hence prevents understanding. The four buttons correspond to the most useful views. More
specifically, it is important to distinguish which views are most useful in the learning process; for this purpose it is convenient to distinguish between a ‘reading mode’ and a ‘signing mode’. This point has been noted and discussed earlier.

Figure 9 shows an example of the reading mode of operation for the letter T. Of the four views, three represent common views in conversational practice, that is, the front and the sides. The bottom left view is the view from the top-front. This is not a view that occurs in conversational practice, but it is useful for checking the position of the fingers.

Figure 10 shows an example of the signer mode of operation for the same letter T. The right top view is the view as perceived by the signer. The other three views are special views. The left bottom view shows the hand as perceived by the signer when the hand is purposely tilted backward so as to check the position of the fingers. The bottom right view also serves to check the correct position of the fingers by eliminating occlusions from all fingers. This hand is discussed in more detail in the next section.

The top left view is the mirror image of what the reader would see. This is useful for checking the correct position of the fingers. A real mirror placed next to the computer display allows for comparison between this view and the signer’s finger spelling so that a check for correctness can be performed. This is impossible using only a mirror and a textbook or other medium in which the correct finger spelling is presented since the mirror returns a left-right inverted image.

By using the window buttons and checkboxes, the user can choose to switch from the four normal views (Front, Back, Right and Left) to the four special views (Top-front, Top-back, Mirror and See-through). See Figure 7 (the window interface).
One of the special views mentioned in the previous section is the transparent view. The ‘see-through’ effect was produced by significantly increasing the value of the transparency attribute of the Lambert shader assigned to the polygonal mesh. The skeleton used to animate the hand was made visible and different colours were applied to the bones of each finger. The bones of the palm and arm were assigned a neutral colour that would not interfere with the colour of the fingers, and a two-colour ramp texture was applied to the nails to create the realistic effect of red nail polish on the top and natural colour on the back.

The hand was made transparent to reveal the position of the fingers otherwise hidden by the back of the palm. Because the hand is only partially transparent, its shape is still clearly recognisable. While the ‘see-through’ effect added clarity to the representation of the hand shapes from the point of view of the signer, the position of the fingers still appeared to be confusing, especially for certain closed hand shapes such as T, N and M, which require crossing and overlapping of fingers. This problem does not occur in quasi-2D cases such as in the popular product Mavis Beacon Teaches Typing (http://www.broderbund.com/Product.asp?OID = 4145160&SC = 1105647&CID = 249) in which the hands are semi-transparent to show the keys but there is no problem of 3D crossing of fingers. The presence of the coloured skeleton offered a solution to this problem: the bones define a clear line of action for each finger, and the contrasting colours help the eye to follow the motion of each individual finger, especially when the lines of action cross each other.
Conclusion
In this paper we have considered a problem of relevance to the deaf community, namely
the development of an element of educational technology to help solve two of the most
serious problems affecting the education of the Deaf: the education of hearing parents
in signing and the education of young hearing-impaired individuals in learning
English.

Within this broad scope we have focused on finger spelling as a primary, essential
feature of all versions of sign language.

As a technique, we have employed 3D animation as the technology of choice since it
offers unique advantages such as (1) infinite number of drills; (2) real-time translation;
(3) unlimited text translation; (4) control over orientation, location and zoom of the 3D
animated hand; (5) control over speed of signing; (6) absence of distracting details
as in photos and films; (7) clarity of 3D scientific illustrations; and (8) possibility of
creating specialised hands.

Using 3D animation we have concentrated on producing a package for the practical
application of learning to read and sign finger spelling. The package includes the pro-
duction of a new realistic hand and automated text-to-sign conversion.

In addition, the package includes the design of a new method of practising reading and
signing by using special views of the finger-spelling hand. The special views include a
mirror image hand and a transparent hand. Several views from the signer (subjective
view) and reader (conversational view) perspectives are also included. Any of the views
can be used for automated translation from text to signing. The text conversion allows
for double letters, pauses between words, and adjustable speeds between letters, words
and sentences.

This work should be regarded as experimental and not as a commercial product
although the package can be used practically and is not simply a theoretical exercise.
Nonetheless, this work is only a first step in the major problem of developing a 3D ani-
mation system for sign language. In this respect this package follows in the trail pio-
nereed by the work of Vcom3D (http://www.signingavatar.com), the first company to
develop a system of 3D animated sign language. In academia very few works in the
same direction have been presented (Toro et al., 2001; Davidson et al., 2001; Sedgwick
et al., 2001).

Although our results are limited to a very small segment of the sign language problem,
we believe the improvements presented here (large-sized realistic hand, specialised
hands and views, differential speed, correct J motion and double formation) can help
develop more advanced systems than the ones currently available.

Many future research topics are opened up by this type of result, including specialised
hands for teaching special topics or audiences, high-speed finger-spelling devices,
parallel finger spelling—closed captioning and quick automated production of finger-spelled printed material.

These and other related topics are in the planning stage.

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