# Sign Language Recognition and Translation: A Multidisciplined Approach From the Field of Artificial Intelligence

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In recent years, research has progressed steadily in regard to the use of computers to recognize and render sign language. This paper reviews significant projects in the field beginning with finger-spelling hands such as "Ralph" (robotics), CyberGloves (virtual reality sensors to capture isolated and continuous signs), camera-based projects such as the CopyCat interactive American Sign Language game (computer vision), and sign recognition software (Hidden Markov Modeling and neural network systems). Avatars such as "Tessa" (Text and Sign Support Assistant; three-dimensional imaging) and spoken language to sign language translation systems such as Poland's project entitled "THETOS" (Text into Sign Language Automatic Translator, which operates in Polish; natural language processing) are addressed. The application of this research to education is also explored. The "ICICLE" (Interactive Computer Identification and Correction of Language Errors) project, for example, uses intelligent computer-aided instruction to build a tutorial system for deaf or hard-of-hearing children that analyzes their English writing and makes tailored lessons and recommendations. Finally, the article considers synthesized sign, which is being added to educational material and has the potential to be developed by students themselves.

Technology is rapidly changing and improving the way the world operates. Barriers for people who are deaf are diminishing as projects of the past two decades have unfolded. Through the use of artificial intelligence, researchers are striving to develop hardware and software that will impact the way deaf individuals communicate and learn. This paper takes the reader on a journey through past and current projects involving sign language and the potential impact these endeavors will have on deaf education and communities at large. Several disciplines of artificial intelligence will be examined: robotics, virtual reality, computer vision, neural networks, Virtual Reality Modeling Language (VRML), three-dimensional (3D) animation, natural language processing (NLP), and intelligent computer-aided instruction (ICAI).

There are some basic concepts regarding sign language that one must understand in order to fully appreciate this discussion. Firstly, sign languages are not international. Many, but not all, countries have unique sign languages. Secondly, American Sign Language (ASL), for example, has its own grammar and rules—it is not a visual form of English. There are, however, sign systems such as "Signed English" that borrow ASL signs but use them in English order. Software is easier to develop for this "transliteration" process than for the true NLP that is required for translating between ASL and English. And finally, signing is a two-way process, which involves both receptive skills (reading the signs) and expressive skills (rendering or making the signs). The reader will find that more progress has been made in terms of computers rendering signs as opposed to reading them.

## Robotics

A robotic hand with the capability of spelling words using the manual alphabet was developed in 1977

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(Jaffe, 1994). Finger-spelling hands were created to assist deaf/blind individuals by replicating the hand-on-hand interpreting of the manual alphabet of a human (Jaffe, 1994). The original model was unable to form the letters that required wrist movement correctly, although a model called "Dexter II" could. By 1992, a robotic hand was developed that was able to produce letters received from a TTY (text telephone) in fluid movements (Jaffe, 1994). Finally, in 1994, Ralph (Robotic ALPHabet; "Ralph," n.d.) was developed. This robot is a "fourth generation computer-controlled electromechanical finger spelling hand" with a menu-driven user interface. Ralph accepts input from a variety of sources including modified caption systems.

## Capturing Signs Through Virtual Reality

The use of capture gloves is one method of allowing a computer to track the movements a person makes and then, through software, expressing it in a spoken or written language. A simplistic glove designed by Ryan Patterson was developed in 2002 in the United States. This 17-year-old's award-winning design involves "... sensing the hand movements of the sign language alphabet, then wirelessly transmitting the data to a portable device that displays the text on-screen" (Thomas, 2002, p. 1). The glove must be trained for each individual's hand much like voice recognition, although training is a quick process. The uses may be limited for Patterson's glove in terms of communication, however, because finger spelling simply spells out English words and is thus equivalent to writing notes.

Gloves that can capture entire signs may be more useful. The "CyberGlove," for example, has 18–22 sensors and is connected to the host computer through a serial cable (CyberGlove, n.d.). Another example, the VPL Data Glove, has sensors that are fiber optic transducers that measure the finger flex angles. Other researchers are experimenting with "mechanical skeletons"—sensors placed directly on a signer's joints—used in combination with an AcceleGlove (Hernandez-Rebollar, Kyriakopoulos, & Lindeman, 2004). More complex capturing systems can involve using a combination of headgear, gloves, and a body vest, which collect more detailed data on the body movements and facial expressions associated with a sign. Virtual reality gloves and suits do encumber the user; however, they are currently more reliable and efficient than using cameras (Hernandez-Rebollar et al., 2004).

## Computer Vision

Another technique to digitize signs involves using computers and cameras to capture hand movements. In 1992, researchers developed a camera that could focus on a person's hand because the signer wore a glove with markings on the tip of each finger and later, in 1994, on a ring of color around each joint on the signer's hand (Starner, 1996). In 1995, Starner began the development of a system that initially involved the signer wearing two different colored gloves, although eventually no gloves were required. A camera was placed on a desk or mounted in a cap worn by a signer in order to capture the movements (Starner, 1996). More recently, a wearable system has been developed that can function as a limited interpreter (Brashear, Starner, Lukowicz, & Junker, 2003). To this end, they used a camera vision system along with wireless accelerometers mounted in a bracelet or watch to measure hand rotation and movement.

The Sign2 Conversion System was designed to convert ASL to written and spoken English (Glenn, Mandloi, Sarella, & Lonon, 2005). Although the current system only involves finger spelling in a controlled environment using computer vision, the long-term goal is translation of full sentences in natural environments including integration with personal digital assistants (PDAs) and smartphones. Currently, several parallel studies are working to improve the percentage of successfully recognized letters or signs (Akyol & Alvarado, 2001; Feris, Turk, Raskar, Tan, & Ohashi, 2004; Lockton & Fitzgibbon, 2002; Terrillon, Pilpre, Niwa, & Yamamoto, 2002).

An educational piece of software, CopyCat, is "a gesture-based computer game for deaf children ... [it] allows deaf children to communicate with the computer using ASL and encourages them to practice signing in an enjoyable way ... the child is asked to wear colored gloves with wrist-mounted accelerometers and sit in front of the computer equipped with a video camera for computer vision recognition system" (Lee, Henderson, Brashear, Starner, & Hamilton, 2005, Game Development section). In pilot studies, children have quickly learned when to push the "attention button" to trigger the computer to watch them sign and are not bothered by the wireless accelerometers.

### Neural Networks

Gloves and cameras can be analogous to a debate over using a mouse or keyboard to enter information into a keyboard—both are just input devices; it is the software that must make sense of the movements. A neural network is a computer program that "learns by example" instead of following a traditional algorithmic approach. "Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques" (Stergiou & Siganos, 1996, section 1.3). In 1993, a neural network was the driving process for a system in which capture was done using a VPL Data Glove connected to a DECtalk speech synthesizer via five neural networks to implement a hand gesture to speech system (Fels & Hinton, 1993). This system recognized a hand shape "root word" and then added an ending to the word based on which of the six directions the hands moved. These "signs" were gestures, not ASL vocabulary. The five networks were strobe time, root word, ending, rate, and stress. By 1999, the CyberGlove was being used to capture signs and then process them using the Stuttgart Neural Network Simulator—a free software package (Weissmann & Salomon, 1999). However, the limitation was that only segmented words could be understood.

### Hidden Markov Models

Another popular method to decipher signs uses Hidden Markov Models (HMMs)—a statistical approach that is used prominently in speech and handwriting recognition. Lee and Xu (1996) used a CyberGlove to capture "gesture" data and then analyzed the data with an HMM. Using interactive software, the computer could associate the gesture with a meaning. In a study by Liang and Ouhyoung (cited by Starner, 1996), continuous Taiwanese Sign Language was captured with a glove and recognized using HMM. A project is also underway to recognize Greek Sign Language using HMM for both isolated and continuous signs (Vassilia & Konstantinos, 2003).

### Additional Sign Recognition Methods

Still other types of machine learning have been called upon to tackle the task of sign recognition. Kadous (1996) designed the GRASP (Glove-based Recognition of Auslan using Simple Processing) system using a simple PowerGlove from a Nintendo game unit as the capture device and then a combination of instance-based and decision-tree learning to recognize the isolated signs. Kadous noted that "Sign segmentation problem is one that remains difficult, since deciding when one sign finishes and the next starts is not easy" (Kadous, 1996, Auslan section). The program thus was designed to learn by example rather than by trying to match signs to a dictionary due to the variability between signers. Bowden, Zisserman, Kadir, and Brady (2003, p. 2) explained: "Recognition [of signs] is . . . performed using markov chains to explain the temporal sequence of events at a word level. Unlike HMMs, the chains can be built from as little as a single training example . . .." It is important to note that whichever method is used, the result is only recognition of individual words—not a translation between languages.

### 3D Animation

Rendering sign language, in the form of 3D animations, is already very sophisticated. One early project used VRML to render ASL finger spelling on the Web (Augustine Su Project, n.d.; Su, 1998). "Avatars" (i.e., synthesized signers, virtual humans, or personal digital signers) are virtual 3D animated images that can sign full words and sentences. Vcom3D (n.d.) develops software that incorporates avatars into educational software lessons for deaf children. Avatars can take the form of different human ethnic types or even an animal. Unlike video, avatars can be manipulated in terms of signing speed and angle. They require much less computing space than traditional video and can automatically transliterate text into Signed English (or another system). Vcom3D (n.d.) reported a research study at the Florida School for the Deaf and Blind in which comprehension of a story increased from 17% to 67% after seeing it signed (vs. being read). Seamless Solutions (n.d.) also reported that none of the students in a study they conducted had difficulty understanding the avatars, including an avatar frog. Another study asked two groups of nonsigners to watch a sign language lesson—with either a digital video or a digital avatar. "It was found that participants learning sign language with the Avatar had a higher learning rate than video" (Naqvi, Ohene-Djan, & Spiegel, 2005, p. 6).

Tessa (Text and Sign Support Assistant) is a virtual post office assistant. When a postal employee voices a predefined phrase, the software chooses the matching motion file and displays that clip of British Sign Language (BSL) for the deaf customer (Cox et al., 2002; Tessa and Simon Project, n.d.). The long-term goal is to process conversations without the domain restraint. In order to acquire the model signs, native signers were captured using a virtual reality suit. Signs for use by the avatar were then analyzed using the HamNoSys coding system. Tessa was on display at the Science Museum in London in 2001 (Cox et al., 2002).

The Simon avatar system transliterates printed text (television captions) into sign-supported English. The benefits of this system are many. It is important to know that ". . . closed captions are not as effective for a deaf person as subtitles in a foreign movie are for a hearing person since the closed captions are not in the deaf person's native language" (Tessa and Simon Project, n.d., Introduction section). Therefore, the first benefit is the ability of the consumer to choose the avatar as opposed to scrolling text. A second benefit is that the avatar is only visible when activated (unlike human interpreting bubbles that sometimes exist on shows and may disturb hearing viewers). They can also be customized depending on the viewer (i.e., a child avatar for a children's program). And finally, Simon is much less expensive than a live human.

Model signs for Simon were acquired from expert signers (Tessa and Simon Project, n.d.) using a CyberGlove (for hand movements), an Ascension Motion Star wireless magnetic body suit (for upper torso, arm, and head positions), and an optical Facetrak device (for facial expression and lip position). When a word needs to be transliterated, it is found in the dictionary and matched to the accompanying physical movement, facial expression, and body positions, which are stored as motion-capture data (not images or video). The ultimate goal is to add an NLP element so that BSL can be shown instead of sign-supported English.

## Natural Language Processing

### Notation Systems

Before examining natural language translation systems, consider how sign language is analyzed by such programs. When spoken languages are analyzed for translation, the software uses knowledge of grammar and other linguistic variables to "understand" the sentence. The components of signs (the features) can be analyzed likewise. A notation system is a way to code the features of sign language. They typically represent hand configuration, hand orientation, relation between hands, direction of the hands motion, and additional parameters (Francik & Fabian, 2002).

Many notation systems for signed languages are available, four of which will be mentioned here. One system, created by Stokoe, Casterline, and Croneberg (1965), was developed to show that the components of ASL fit together to form a linguistic structure comparable with that of spoken language. There are 55 symbols covering all the parameters ("Sign Stream," n.d.). Secondly, the HamNoSys system was developed as a scientific/research tool in the 1980s (Hanke, 2004). It consists of 200 symbols covering the above-mentioned parameters. Transcriptions are precise but long and cumbersome to decipher (Tessa uses this method). Thirdly, the Szczepankowski System is the method used in the THETOS (Text into Sign Language Automatic Translator, which operates in Polish) project (Francik & Fabian, 2002).

Finally, Sign Writing was invented by Valerie Sutton in 1974 ("SignWriting," n.d.). It contains over 600 symbols and can describe all the parameters mentioned above. Sign Writing is useful for studying ASL grammar and is more "readable" to people than the other systems. A free DOS-based software program is available to type the symbols (Gleaves & Sutton, 2004). Researchers are now able to convert Sign Writing into SignWriting Markup Language and subsequently into virtual reality animation sequences using MPEG-4 coding techniques (Papadogiorgaki, Grammalidis, Sarris, & Strintzis, 2004). A Web online tool allows users to convert text to animated sequences rendered in an avatar of choice.

### Current Projects

Research projects integrating a translation component are currently underway. According to the THETOS project:

> Translation is the process in which one puts to the input a text which consists of words not supplemented by any hints, on output one gets a text of equivalent content, under the form of a sequence of signs, and the transformation of the input text to the output one is done without man's interferences. It acquires input data in the form of a text file, provides its full linguistic analysis (morphological, syntactic, and semantic) and finally produces the output in the form of an animated sequence ("THETOS," n.d., Introduction section).

THETOS is used in Poland in medical settings where personnel type a question into the system, which will in turn analyze the phrase and decide what animation should be created to render the same message in Polish Sign Language. A word does not have a "matching sign" per se—it has characteristics that when put together result in a sign. The animation technique used by THETOS is "OpenX" (Suszczanska, 2002; Szmal & Suszczanska, 2001).

Another developing project, Paula, was started with the goal of creating a portable system to translate English to ASL ("Computer program," 2002; Sedwick, 2001). One of the first planned applications of Paula will be airport security. The research team also wants to use her to replace closed captions much like the Simon project described earlier (Paula Project, n.d.). The first step in the Paula Project was to create a database of signs to be used as the lexical database for the translator. This project did not capture the model signs through virtual reality but took a different approach because motion-capture data was thought to be too inaccurate and is recorded in numerical terms that are hard to modify. Paula instead uses an animation software package that has been customized for sign transcription (Paula Project, n.d.). A successful pilot test indicated that the finger-spelling animation was easy to read (Davidson, n.d.). The team then proceeded to build a dictionary of complete signs by selecting hand shapes and positions from a friendly menu-driven interface using the same animation software (Furst, 2000; Tomuro, 2000; Toro, 2001). Currently, work on Paula is focused on adding the NLP component.

A system entitled TEAM (Translation from English to ASL by Machine) was begun but appears to have been discontinued. It used a Lexicalized Tree Adjoining Grammar-based system for the NLP step (Zhao, n.d.). Another project using Australian Sign Language (Auslan) is a tutorial package for learning signs. It uses a 3D avatar and has a sign-editing interface where new signs can be designed. The current research focus is on adding a grammar parser so that translation can be possible and can further aid students in learning Auslan (Yeates, Holden, & Owens, n.d.). There also is a multimedia database tool, created in 1997, called the "SignStream Project" which contains digitized video data and a representation of the data in a linguistic format (Kiernan, 1997).

## Intelligent Computer-Aided Instruction

An example of ICAI is the ICICLE (Interactive Computer Identification and Correction of Language Errors) project ("ICICLE Project," 2002). ICICLE is "designed to provide writing assistance for second language learners of English, specifically American Sign Language natives. The system will analyze written English texts from deaf individuals, identifying possible errors and generating tutorial text tailored to each writer's level of language competence and particular learning strengths" ("ICICLE Project," 2002, Overview section). ICICLE combines ICAI with another domain of artificial intelligence—NLP. In this case, the NLP has a tougher job than with "regular grammar checks or translators" in that it has to not only analyze the English writing but also do so taking into consideration the typical errors present in deaf writing samples and thus inferring what the writer "meant" (McCoy & Masterman, 1997; Michaud, 2000).

The main modules of ICICLE are therefore "Error Identification" and "Response Generation." In the first module, the writing is analyzed (Michaud, 2001) using a combination of a TRAINS text parser, a COMLEX Syntax (lexicon which contains 38,000 different syntactic head words and grammar rules), Mal-rules (the typical errors made by deaf learners), and SLALOM (the steps of language acquisition in a layered organizational model—the knowledge base). The previous data collected on the user must also be drawn upon in order to properly evaluate not only which errors were made but also what concepts are within the student's ability to address at this point. For example, if a student typed "She is teach piano on Tuesdays," it would be up to ICICLE to determine based on the sentence itself and the level of the student (Michaud & McCoy, 2002) whether the desired meaning was really "She teaches piano on Tuesdays" (a beginning sentence structure), "She is teaching piano on Tuesdays" (an intermediate structure), or "She is taught piano on Tuesdays" (an advanced structure). The second module is responsible for then instructing the student on the appropriate grammar lesson in an individualized manner. The response is currently in English, but the goal is to use an avatar to explain in ASL, thus increasing the effectiveness of the instruction.

## Application

Aside from the education-based projects already discussed, the ability of students to create their own work through sign language-related authoring software may have lasting benefits. Authorware gives the user the ability to create their own avatar translations for inclusion in videos, Web sites, and more. It requires the students to study and use the knowledge of ASL (or another sign language's) grammar, which frequently has been omitted from deaf education in the United States. A rudimentary software program, developed originally for Sign Language of the Netherlands, is available free of cost and allows the user to create animated sequences in any sign language. The user must construct the animations from scratch, but it is still useful for basic skill building (Vsign Project, n.d.). The first commercial sign language authoring product, however, was recently released. It is called the Sign Smith Studio and features nonlinear editing tools with five different tracks: speech, gaze, expression, cosign, and sign. It contains a dictionary of 2,000 signs and will automatically transliterate from written English to Signed English. Words that have multiple meaning will be appropriately selected automatically. In addition, if the user knows ASL, he can manually translate sentences by organizing the signs and facial expressions appropriately. There are 12 different avatars from which to choose. The resulting scripts may be published to Web sites and CD-ROMS because they are VRML based (Vcom3D, n.d.). Authorware places the power of technology directly in the hands of the instructors and students.

The look and function of sign dictionaries may also be revolutionized by new computer-based sign language technologies. Currently, in order to look up a sign, one must know the English equivalent, but with virtual gloves, the user could sign the word and have the computer find the definition. Hearing students learning sign may also benefit perhaps through sign proficiency evaluations. Tests might one day be translated from English to ASL so that teachers could evaluate what content deaf students understand apart from their understanding of English or another language. Deaf children could also establish "pen pals" in other countries using software that translates from one sign language to another. Still another application of this technology is the Relay Phone or Internet Service, whereby a hearing interpreter must serve as an intermediary during conversations between deaf and hearing persons. This third party could be eliminated with the use of translating avatars in some situations. Likewise, in the field of educational interpreting, limited activities could potentially be interpreted by an avatar in cases where qualified interpreters were not available. When better software for true translation is developed, at a cost that is not prohibited for schools, there could also be better access to textbooks in native languages.

## Conclusion

Sign language recognition and translation is an active area of research. Nevertheless, there are many questions waiting to be explored. Does using different avatars to sign various concepts in a lesson contribute to deaf students comprehension or memory of the instruction? Will computers ever be able to translate basic conversations accurately, let alone complex poetry, music lyrics, and other vague concepts? Only by continuing to conduct research and probe into these issues will it become clear whether the artificial intelligence contributions of the past two decades will change course or continue on their present path with added fervor.

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