Technical Sciences
Brassersplein 2
2612 CT Delft
P.O. Box 5050
2600 GB Delft
The Netherlands

www.tno.nl

T +31 88 866 70 00
F +31 88 866 70 57

TNO report

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Automated Sign Language

Date	June 26th, 2014
Author(s)	Martin Prins Joris B. Janssen
Reviewer	Rob Koenen
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Management Summary

Title :	Automated Sign Language
Authors(s) :	Martin Prins
	Joris B. Janssen
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This report provides an overview of a Proof-of-Concept for a signing avatar service. The Proof of Concept was created by TNO in an assignment from the Research and Development department of the Directorate Distribution and Broadcasting of the Netherlands Public Broadcasting Organisation (Directie Distributie en Uitzending, Nederlandse Publieke Omroep), the NPO. In 2012, the NPO asked TNO to investigate the feasibility of a signing service for children's TV-programs based on a virtual character, a so-called avatar. The NPO believes that such technology could significantly increase the number of programs that can be made more accessible to deaf and hard-of-hearing children.

Working closely with the NPO, TNO first performed a feasibility study, which consisted of a decomposition of the problem area, an analysis of the state of the art, and interviews with experts in the field of sign-language. We concluded that several technical challenges need to be resolved to be able to create an avatar-based signing service, notably:

- Translation of text to sign language;
- Providing signs in a format that can be interpreted and rendered by avatar rendering software;
- Fluently rendering the signs by an avatar, synchronously with the program.

Based on the current state of technology we concluded that it is not feasible to allow an avatar to sign according to Nederlandse Gebarentaal (NGT, Dutch Sign Language), but that a solution based on Nederlands met Gebaren (NmG, Dutch with Signs) probably *is* feasible.

Following the assessment of the state-of-the-art, we developed a Proof-of-Concept, which uses the Signing and Gesture Markup Language (SiGML) for rendering signs by an avatar. In the PoC, an episode of the children's TV-program Zandkasteel was enhanced with a signing dinosaur-avatar which renders signs according to NmG.

This Proof-of-Concept was evaluated in a user evaluation, in which 16 deaf and hearing-impaired children aged 6 to 8 watched the content and filled out a (pictorial) questionnaire. The experts, the children and the teachers involved in the user evaluation all expressed their enthusiasm for this new technology, and indicated that the signing avatar clearly added value to the experience of watching a TV-program for this target audience.

The study also revealed that not all information provided in a script needs to be signed by the signing avatar, which eases the creation of a signing avatar service. Other findings include:

- A single avatar design can be repurposed for different characters in a TV-show, by merely changing its colour;
- Whilst the non-manual components of signing (facial expression) constitute an important aspect of signing, the evaluation shows that even when the non-manual components are limited or, in some cases, even incorrect, the children were still able to understand the signs.
- Creation of the PoC required relatively large portion of manual labour.

Based our the findings we estimate that a fully automated workflow, suitable for integration in a broadcaster workflow, will not be possible within 5 years and probably even longer. On the other hand, the user study shows the need and added value of such a service at the present time. It therefore will be beneficial to further explore semi-automated solutions.

We recommend that the NPO investigate the feasibility of adding metadata to scripts which can greatly ease the translation to Nederlands met Gebaren, which is the most labour-intensive step in the process. Just calling out the words to be signed in the script might make it much easier to provide avatar-based signing.

Our main recommendation to the NPO is to continue this research in a European collaborative setting, as many of the remaining key challenges are independent of the respective sign language. Additionally, economies of scale will make avatar-based signing services in the short term much more viable if the underlying technologies can be used across Europe – or even beyond.

Further research and development will boost the accessibility of television programs for children who can greatly benefit from having access to more content.

Glossary

Name	**Definition**
Avatar	Virtual Character that can be animated
NGT	Nederlandse GebarenTaal (English: *Dutch Sign Language)*
NMG	Nederlands Met Gebaren (English: *Dutch with Signs)*
SIGML	Signing and Gesture Markup Language
Signing Avatar	A Virtual Character that can perform sign language
PoC	Proof-of-Concept
D	Doof (English: *Deaf)*
SH	Slechthorend (English: *Hard-of-hearing)*

Contents

1 Introduction

In 2012, the Dutch Public Broadcaster (NPO) approached TNO with several questions regarding its media services. Specifically, the NPO was interested in finding out to what extent media technologies could be used to offer additional services for people, especially children, with hearing impairments.

The NPO currently provides signing services for selected programs, such as news broadcasts and special national events. Unfortunately, the NPO cannot provide signing services for each program that is broadcasted, due to the high cost associated with these services (signers, broadcasting studios, broadcasting channels).

Technological advancements may, however, enable other new approaches for offering accessibility services for hearing impaired people :

- Hybrid Broadcast Television (HbbTV) provides a novel way to combine broadcast with broadband services, and thus new methods to provide accessibility services into the living room.
- Avatar or virtual character rendering technologies can be used to render signs, and in theory provide a complete virtual way to render sign languages such as Nederlandse Gebarentaal (NGT[1]) and Nederlands Met Gebaren (NMG[2]).

Therefore, the NPO have asked TNO to investigate whether it would be possible to provide signing services based on virtual avatars, such that in the future many more of the NPO's content may be made better accessible to children, and eventually also adults, with a hearing disability.

"This report describes the outcome of the signing avatar project, a joined effort by the NPO Development, Directorate Distribution and Broadcasting and TNO."
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In this project we created a Proof-of-Concept ("PoC") based on the Signing and Gesture Markup Language (SIGML) using an episode of the popular TV-program Zandkasteel[3] ("*Sand Castle*"), which is a Dutch/Belgian original series featuring several life-size puppets. We evaluated the PoC last March in a user study with deaf and hearing impaired children aging 7-10.

This report is structured as follows:
Chapter 2 provides some background and provides a short summary of the feasibility study that was performed.
Chapter 3 gives an overview of the Prototype implementation that has been created for the Proof of Concept.
In Chapter 4 the User evaluation is presented, and it's findings are discussed.
Chapter 5 provides the findings of the Proof-of-Concept and discussion. It also provides suggestions to how the findings presented in this report can be used by the NPO.

[1] NGT: "Dutch Sign Language"
[2] NMG: "Signed Dutch"
[3] Zandkasteel website: http://jeugd.ntr.nl/zandkasteel/

2 Background

In 2012, the NPO asked TNO to study the feasibility of creating accessibility services based on signing avatars[4], as a novel way to extend accessibility services for deaf and hearing impaired viewers in the Netherlands. A short summary of the findings are given in this chapter. The chapter however is started with some background information regarding sign languages.

2.1 Sign language

Sign language is a visual-manual form of communication, in which concepts are proceedings are presented visually by means of gestures. Similar to spoken languages, there are many different signs languages worldwide. These sign languages use the same base principles, e.g. the usage of different visual distinguishable components (articulators), which combined represent a sign. Time (movements) and space (the location where signs are position w.r.t. the body) play an important role in sign languages.
A sign typically is created with:

- Hands
- Facial expressions
- Shape of the mouth
- Body posture.

The hands are called the *manual component* of a sign, the other components are non-manual.

In more detail, a sign is a combination of:

- A hand shape +
- A place or location (of the hand in signing space)+
- Orientation (of the hand) +
- A movement (of the hand) +
- The facial expression of the person that is signing.

All these aspects contribute to communication of a sign and the interpretation by the person who is reading the sign. If one or multiple components are not articulated correctly, the signs can be misinterpreted or not understood at all.

2.1.1 Sign languages in the Netherlands

There are two sign languages in the Netherlands:

- Nederlandse Gebarentaal (NGT)
- Nederlands met Gebaren (NmG)

NGT is a stand-alone language, independent of Dutch. Mimicry is part of the grammar of NGT (e.g. raising an eyebrow means asking a question). NGT does

[4] TNO, "Haalbaarheidsstudie Automatische Generatie Gebarentaal" . TNO report R10325. 31-08-2013. (In Dutch).

have many sign-equivalents for Dutch words, but the syntax of sentences is different from Dutch. For instance, a verb is always the last word of a sentence in NGT.
NmG is not a stand-alone language, but a mixture of Dutch and NGT. NmG is typically used as an extension to Dutch: Dutch spoken text is complemented with signs according to NGT but according to Dutch grammar and syntax rules. The spoken words are signed consecutively.

Which language is used depends on multiple factors:

- Whether a person communicates with a deaf and hearing person concurrently (NmG is mostly used).
- Whether the communication is between deaf persons only (mostly NGT).
- Whether the person who is communicated with has a cochlear implant (mostly NmG).

2.1.2 *Intended* audiences

The actual number of deaf and hearing impaired people in the Netherlands is not known. Estimates range from 5000 to 33000 people. One estimate states that there are 1.4 million people with a hear deficit in the Netherlands, but this also includes elderly people who get a hear deficit due to aging.

Sign languages are also used by other persons:

- People with severe speech sound disorders.
- Relatives of deaf and hearing impaired people.

2.2 Feasibility study

This feasibility study consisted of several parts:

- A problem analysis and decomposition
- An analysis of the state of the art in signing avatar solutions.
- Interviews with Dutch sign language experts and researchers.
- Identification of technical challenges that need to be resolved to provide a solution in which a signing avatar feature could be automated, e.g. to see if it is feasible to convert a transcript of a TV program to Dutch sign language, which could subsequently be rendered by an avatar.

2.2.1 Problem analysis and decomposition

The research question for the feasibility study was formulated as follows:
To what extend is it possible to automatically translate Dutch text to sign language, such that it can be signed by a virtual character?

The research question was divided in sub questions by decomposing the problem in several topics, which would need to tackled:

- Acquisition of spoken language, from a (tran)script or subtitles, or speech recognition if necessary.
- Detection of sentence constructs in the spoken language.
- Translation of a sentence in a series of signs, which consists of:

  - Understanding the sentence grammatically
  - Translation of Dutch grammar to the grammar according to NGT
- Translating the signs into a format which can be rendered by avatar software
- Rendering the series of signs using a computer-controlled avatar.

This decomposition is also given in Figure 1, which provides a system which can potentially do the above.

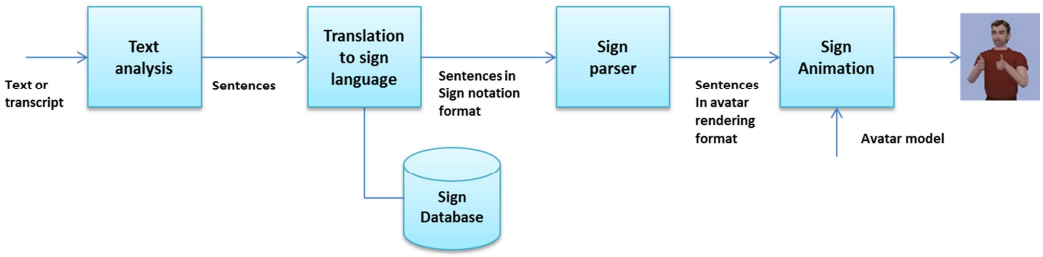

Figure 1: Decomposition of a system for the automatic generation and animation of signs based on textual input

This decomposition was used as a starting point for the analysis of the state of the art, but also in the interviews with experts.

2.2.2 Observations

One of our first observations was that it is extremely difficult to provide, with currently available technology, an automated solution that translation written text into a sign language. Basically the components required for translating spoken Dutch to NGT are not yet available. The feasibility study thus made clear that providing a virtual sign language interpreter using full NGT would not yet be possible, because the automatic translation is an unsolved problem. We therefore opted to provide signs as a complement to the audio and visual information, as a form of NMG.
Providing smooth and natural gestures, both manual and non-manual components by an avatar rendering engine provides another challenge, albeit less insurmountable.

We did however find existing solutions for analysing and interpreting Dutch texts. These could potentially be used in combination with a solution which uses NMG instead of NGT, as we would not need to translate to a different grammar.

At the same time, we identified that if we would be able to provide a solution that could offer even limited value to deaf or hearing impaired children, it would be worth investigating. This was confirmed by several sign-language experts and teachers we spoke to during the feasibility study, and this view is firmly shared by the NPO.

We identified a technology which could be used to implement a credible Proof of Concept, meeting several scalability and operational criteria:

1) Sentence constructs is provided on the basis of concatenating individual signs;
2) Once created for one program, signs can be reused for other programs;
3) The technology is language agnostic/independent. This means that the technology can be used to describe signs according to Dutch Sign Language, but also be used for other sign languages (German, English, etc).
4) The technology can be used to control animation software which can express sign language in real-time.

The technology is described in the next section.

2.3 Signing and Gesture Markup Language

The usage of avatars for signing purposes has been addressed in several European research projects in a number of research topics:

- Automatic detection of gestures based on motion-tracking suits or video recordings
- Automatic recognition of spoken text (*speech recognition)*
- Translation of text to sign language
- Translation of sign language notation to rendering notation
- Precise animation of gestures by virtual characters.

Our project focused on sign language synthesis from scripts, which is covered by the latter three areas. One of the major developments in Europe is the Signing and Gesture Markup Language.

The Signing and Gesture Markup Language is an XML based markup language for synthesizing and animating (rendering) gesture sequences.
It was developed within the European research projects Visicast, eSign[5] and LinguaSign[6], and builds upon the HamNoSys[7] sign language notation system.

SIGML describes the actions that need to be performed to render a sign. This might include, for instance, the position of the index finger, the movement and direction of an arm or the relative position of a manual part to the body.
Figure 2 gives an example of a sign in SiGML notation.

[5] http://www.sign-lang.uni-hamburg.de/esign/
[6] http://www.uea.ac.uk/computing/the-linguasign-project
[7] Hamburg Notation System or HamNoSys is a phonetic transcription system for sign language developed at the University of Hamburg. It uses a symbolic notation system for describing signs.

```
<sigml>

<hns_sign gloss="BAL">
        <hamnosys_nonmanual>
            <hnm_mouthpicture picture="bAll"/>
            <hnm_body tag="TF"/>
            <hnm_head tag="ND"/>
            <hnm_eyegaze tag="DN"/>
            <hnm_eyebrows tag="RB"/>
            <hnm_eyelids tag="SB"/>
        </hamnosys_nonmanual>
        <hamnosys_manual>
            <hamsymmlr/>
            <hamfinger2345/>
            <hamthumbopenmod/>
            <hambetween/>
            <hamfinger2345/>
            <hamthumbopenmod/>
            <hamfingerbendmod/>
            <hamextfingeru/>
            <hambetween/>
            <hamextfingerol/>
            <hampalml/>
            <hambetween/>
            <hampalmdl/>
            <hamparbegin/>
            <hammiddlefinger/>
            <hamfingertip/>
            <hamplus/>
            <hammiddlefinger/>
            <hamfingertip/>
            <hamparend/>
            <hamtouch/>
            <hamshoulders/>
            <hammoveo/>
            <hamsmallmod/>
            <hamfast/>
        </hamnosys_manual>
    </hns_sign>

</sigml>
```

Figure 2: Example of SIGML notation. The example presents the NGT representation of the word “ball”

Sign languages consist of manual and non-manual parts. The manual parts include of all the arm, hand, and finger actions. The non-manuals consist of all other parts of a sign: facial expressions, mouth movements, etc. Both components are described in SIGML. In the example above, this is given by the <*hamnosys_nonmanual*> and <*hamnosys_manual*> respectively.

SiGML can be used to describe individual signs, as seen above, but could also be used to describe entire sentences. Sentences can be constructed based on an

existing vocabulary of signs. The more new signs are created and added to the vocabulary, the less new signs need to be created when the technology is used for new TV content.

Experts told us that as a ball-park figure, around 300-500 signs[8] would be required for a TV program targeted for young children:. NGT uses identical signs for similar concepts, so 500 signs would approximate around 1500 words in spoken and written Dutch.

Experts also pointed us to two existing repositories of Dutch signs, which could be used for a PoC:

- A collection of 130 signs from the LinguaSign[9] project.
- A collection of 1776 signs from the GebarenNet[10] project.

[8] This number does not take into account the variations on basic signs due to changes in spatiality (which lead to adjustments in the manual component) or whether the sign is the last phrase in a sentence (which lead to adjustments in the non-manual component)..

[9] http://linguasign.com/about.html

[10] The GebarenNet website unfortunately is not available anymore. Some information (in Dutch) about this project is given at: http://www.doof.nl/nieuws/gebarennet-nl-gebarentaal-via-internet/24724

3 Prototype Implementation

To see to what extent SiGML could be used as a technology to provide a signing avatar service, we designed a Proof of Concept, which would use SiGML and transcripts of the TV-program Zandkasteel to create a signing avatar which would show signs during the TV-show. In this chapter, we describe the design of the PoC, the actual implementations, and conclude with the findings during implementation.

3.1 Design

The feasibility study showed that a fully automated workflow would not be possible given the state of the art. It also showed us that, although we would like to use NGT in the PoC, this would not be possible due to the technical challenged involved.

We therefore focussed on what we deemed possible at the time: creating a Proof-of-Concept aiming at providing supportive signs for a TV program with the following criteria:

- use NmG as supportive sign language;
- use technologies based on SiGML;
- use automated processes where possible, and:
- use a workflow that in potential could be used by a broadcaster.

We depicted a scenario for a signing avatar service that would consist of a semi-automated workflow, in which text analysis and speech analysis technologies are used to parse text / audio input to determine which information is communicated to the user in aural format and thus would be eligible for signing for accessibility services. A workflow for such a service is given in the following diagram.

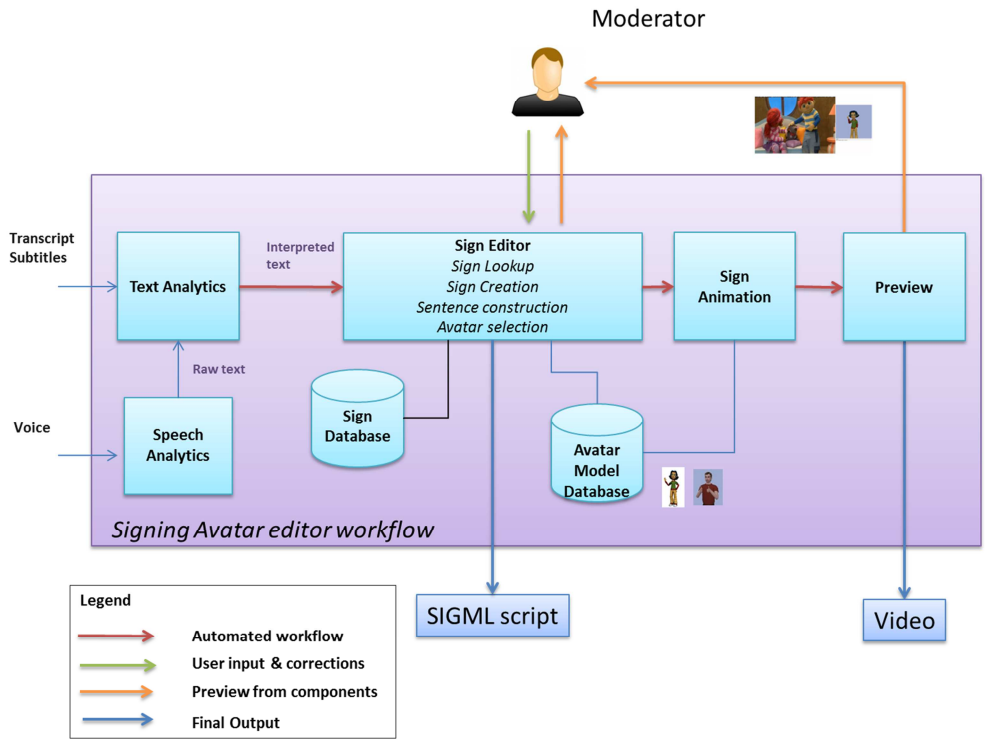

Figure 3: Workflow for a signing avatar service

In this workflow the textual input is automatically analysed, providing the Sign Editor software with text that needs to be signed. This Sign Editor software is operated by a Moderator, which is a person skilled in sign language and in operating the Sign Editor software. The Moderator can be presented with a first, raw, automatically generated signing script, which can be previewed and edited. Based on the (live) previews, the Moderator will be able to make the following adjustments:

- Create new signs
- Improve existing signs
- Resolve interpretation matches (incorrect interpretations made by the Text Analytics module)
- Resolve mismatches (i.e. signs that were incorrectly selected)
- Select alternative signs which might be better suited for the content of the TV program.
- Alter timing of gestures.
- Change and select avatar models.

Once the Moderator is satisfied the final signing script and/or the final avatar rendering video can be created.

3.1.1 *Availability of technological components*

We identified several software components for potential use in the PoC:

- *JASigning*[11]; a virtual signing system developed at the University of East Anglia. Its SiGML URL Player and SiGML Service Player can render signs

[11] http://vh.cmp.uea.ac.uk/index.php/JASigning

provided in SiGML syntax by virtual characters. The former takes SiGML files, or URL's to SIGML files as input; the latter is controlled by sending SiGML signs by transmitting them over a network socket (and thus allows for live / real-time input).
- *eSIGN Editor*[12]; a tool for creating / managing SiGML signs developed at the University of Hamburg.
- Several avatar models:
    - The character models that where created for the LinguaSign project, by TestaLuna[13].
    - Several character models created by the University of East Anglia (UEA), courtesy of UEA.

3.2 Implementation

With the design in mind, we created a Proof-of-Concept based on the available software components. The implementation process consisted of several steps, which will be presented in the following paragraphs:
- Content selection
- Content analysis
    - Transcript analysis
    - Video analysis
- Sign creation / script construction
- Video creation

3.2.1 Content selection

Several TV shows were initially considered for the POC, including Jeugdjournaal, Sesamstraat and Zandkasteel. A final selection was made based on several criteria: the target audience of the TV-program, the complexity of the spoken language, the amount of spoken words, and, related, the program's vocabulary.

We selected Zandkasteel as the most appropriate program, due to the limited complexity of the language used (an episode features approximately 150 different words), and the target group, i.e., young children aged 4-10. Programs for older children would probably have benefited more from subtitling, while for young children who are not yet able to read this would be no viable alternative. An additional benefit of opting for Zandkasteel is the fact that it is produced by the Dutch Public Service Broadcaster NTR (jointly with the Belgian VRT); the NTR is a member of the NPO.

3.2.2 Transcript analysis

The NPO provided transcripts from several episodes from Zandkasteel. The transcript contain the sentences that are spoken, with the respective character and time offset. It also contains non-spoken explanatory descriptions, for instance stating what a character is doing.

The transcripts were analysed with text analysis software to determine the number of unique words per episode (verbs, noun, adjective, pronoun, names, etc.).

[12] http://www.sign-lang.uni-hamburg.de/esign/annualreport2003/editor2003/editor2003.html
[13] http://www.testaluna.it/

These words would need to be translated into their respective sign representation in NGT. This list was compared with the existing SiGML vocabulary.

Episode	Total number of words	Unique words[14]	Matches with existing collection[15]	Words Not yet available
ZKscript_119	545	189	100	89
ZKscript_66	489	142	76	66
ZKscript_67	434	176	100	76
ZKscript_69	511	198	98	100
ZKscript_70	550	179	97	82
ZKscript_75	369	116	58	58
ZKscript_76	524	198	84	114
ZKscript_81	462	154	85	69
ZKscript_82	368	150	79	71
ZKscript_97	670	205	110	95
Zandkasteel-lied	98	41	22	19
Zkscript_108	419	158	88	70

Table 1: Text analysis of Zandkasteel transcripts. Includes 11 episodes and the theme of the show (Zandkasteel-song)

The analysis showed that Zandkasteel uses a limited set of words: around 120~200 unique words per episode.

[14] Note: several filters where applied: conjugations of verbs where counted as one verb; articles were removed (not part of NGT); comments were removed.
[15] Note: the analysis did not take homonyms into account, so the matches may contain false positives.

As the episodes have overlap in words, a second analysis was performed to determine this overlap, but also to determine the additional effort that would be needed for additional episodes, once all the missing words for an episode had been created. In this analysis an optimal sequence order was determined to produce signs for each episode[16].

Episode	New words needed	Aggregate of words needed
Zandkasteel-lied	19	19
ZKscript_75	48	67
ZKscript_66	45	112
Zkscript_108	42	154
ZKscript_82	42	196
ZKscript_81	42	238
ZKscript_70	41	279
ZKscript_67	40	319
ZKscript_97	50	369
ZKscript_119	50	419
ZKscript_69	50	469
ZKscript_76	70	539

Table 2: Analysis of the words that would be needed to be created as SiGML signs.

This analysis shows that the number of new words that need to be created per episode is fairly constant (around 50) and that the total number of signs needed is 539.
The results indicated that Zandkasteel uses a limited set of words and that there is a relatively large overlap between words used in several episodes, but also that each new episode deals with new subjects, which means that new words remain necessary. This makes sense as Zandkasteel targets a specific domain and has a limited number of characters, which play in or around the Sand Castle. Whether the amount of new words that would be needed for additional episodes would decrease is assumed, but not verified.

Other observations from the analyses:

- Not all words in the transcript are valid concepts in Dutch. I.e. the writers are sometimes creative with words when writing a script, and may use their own words that are usually a combination of (two) existing words. The listening audience will understand what is meant, but these words can be hard to translate into a sign or combination of signs.
- Not all words/sentences in the transcript are (literally) spoken by the characters. Also the timing may be incorrect. This will make full automation complex.
- Words can have different meanings based on the context (i.e. homonyms), and often these homonyms have different signs. The correct meaning could be established by looking at the sentence or the wider context, including the video (the image). This would be obvious for a viewer, but the required disambiguation is rather complex when this needs to be done by software.

[16] Beforehand we did not know how many episodes we would be able to support in the PoC. So we determined the optimal order to create signs for and episode such that for each subsequent episode the additional effort was minimal, by having an optimal reuse of existing and newly created signs.

This means that correct automatic interpretation of spoken words to respective signs is a challenge, especially when the input (in this case the transcript) does not correspond entirely to what is being said in the actual video. We expect that adding metadata in the transcript with respect to signing purposes could help reducing the complexity of the process of correct interpretation and determining what needs to be signed.

It is unclear what the effect will be when using subtitles instead of a transcript. Subtitles contain less descriptive data, but may use simpler language constructs.

Finally, transcript analysis showed that episode 75 (ZKscript_75) would be a good candidate for the PoC evaluation, as it required the least amount of new signs: 19 for the theme and 48 for the episode itself. This episode was therefore chosen as the (first) episode that would be provided with signs.

3.2.3 Video analysis

The prior analysis gave insight in the words that are spoken in the episodes. These words do, however, not necessarily correspond to the words that need to be signed. Some information may already be provided to a viewer by just watching the video, without hearing the audio.
To determine which words would actually need to be signed, a deaf sign language teacher watched episode 75, which is titled “Finnie is Lief” while looking at the transcript. He highlighted all the parts of the transcript that were not clear from just looking at the video. This made it clear which words needed to be provided by signs.

Based on the video analysis and text analysis we made a final selection of words / sentences to be signed by the avatar.

3.2.4 SiGML sign creation

For each spoken sentence that would need to be signed by the avatar, its equivalent in NmG needed to be created. These sentences therefore would then be presented in SiGML notation. This required the availability of the respective words in SiGML notation. As discussed before, we could reuse some existing signs that were already available, but the other signs were created for the PoC by two sign language experts of Radboud University, who were already familiar with SiGML and the sign construction software. The sign creation process gave important insight into the effort required to create signs in SiGML notation:

- It takes about 10 minutes to create a basic version of a new sign in SiGML notation
- It may take a multiple of the above to optimize or tweak a single sign, when the end result (a preview rendering by the avatar signing software) is not exactly what the sign-editors expected it to be. This can have several reasons:

  - the rendering is incorrect (i.e. parts of signing are not good). We notably observed this with the non-manual components of signs (the facial expressions).
  - a rendering of a sign is considered not good enough (the editor would like the sign to look better). Examples where body movements that looked rather non-natural.
- It seemed that the majority of the signs could be created with little effort, but the ones that proved difficult to create required significant additional work.

Rendering Non-manual components
A main limitation of the implementation of the SiGML based software is the limited support for providing visual expressions, which is a really important part of sign language. A concern by the sign-editors was that the avatar would not be able to provide these expressions sufficiently, and that therefore the people viewing the signs would either not understand them, that they would misinterpret them, or that the signing avatar would look unnatural.

Therefore, this was an important aspect that needed further investigation in the User evaluation.

3.3 Avatar considerations

3.3.1 Avatar design

As presented in section 3.1.1 several avatar designs were made available for the PoC.
During the PoC development process, it became clear that, whilst the avatars could be used to render signs, they were less suited for usage with the Zandkasteel content. This had several reasons:

- technical limitations of the software with respect to supported body movements,
- the fluidity of the motions
- the avatar designs.

Figure 4: The Luna and Siggi avatar model from the LinguaSign project

The avatars that were used initially had a human-like appearance. An example is the Luna model as presented in Figure 4.
During initial tests with these avatar models we received feedback that the

movements were non-natural or "*robotic*". Since we would not be able to improve this very much, we decided, after discussion with researchers and avatar designers, to use an avatar that doesn't have a human appearance. We argued that viewers would probably be more accepting of non-natural behaviour if the avatar looked cartoonish or animal-like. The effect of observers being less accepting of artificial-looking gestures by human-like avatar is known as the *uncanny valley*[17].

An alternative avatar design was created that was child-friendly and that observers would expect to show only limited facial expressions[18]:

Figure 5: Example of the dino avatar

Positive aspects of the dino design compared to the other avatar models:

- Neutral colour usage.
- Higher contrast between hand and body
- Option to make the hands larger, which aids in reading the signs

The new avatar design also had two drawbacks:

- The change in body posture required adjustments to some of the signs.
- The mouth and jaw of the dino caused problems with some mouth expressions.

The new avatar design had a different, more voluptuous body structure compared to the earlier human based designs. This caused some problems with the rendering of some of the signs, such as collisions between hands and face, hands moving through the belly. This required some tweaking of the character design, but also (manual) corrections to a couple of signs that were suitable for the old avatars but not of the new models.

Due to the mouth composition, it was more difficult to see differences between expressions being made with the mouth. Especially, rendering an O-like shape proved difficult.

[17] Gee. F.C. et al, "Uncanny Valley Revisited". 2005 IEEE International Workshop on Robots and Human Interactive Communication.
http://www.hci.iastate.edu/REU09/pub/Main/BiologyInVRBlog/Uncanny14.pdf
[18] The Dino avatar is based on the following design:
http://tf3dm.com/3d-model/cartoon-dino-32868.html

Also, it is important that signs can be read as easily as possible. This implies the following:

– There should be a large contrast between the hands and the body, as this facilitates reading the signs when presented in front of the body.
– The torso of the avatar character should be as neutral as possible, using a uniform colour. A logo or animation on the belly therefore was not suitable.

3.3.2 *Role of the signing avatar*

Making clear whose speech the avatar is expressing was another puzzle we needed to solve. Zandkasteel consists of a narrator and three (speaking) protagonists, Koning (“King”) Koos, Sassa, and Toto. TV signing services typically use a sign language interpreter, which acts as narrator, but also signs what all characters / people are stating.

We therefore needed the ability to distinguish between the several protagonists and the narrator. We had several character models at our disposal, but only the Luna character seemed suitable (at first glance). To distinguish between the protagonists and the narrator, several alterations of the Luna design were created, by changing the texture:

- A pink shirt would represent the girl Sassa
- A blue shirt would represent the boy Toto
- Etc.

We showed this solution to the test panel, which reacted positively to this solution for addressing multiple characters with just one avatar design, so this approach was kept for the final version (based on the Dino-character design).

The resulting character designs are given below:

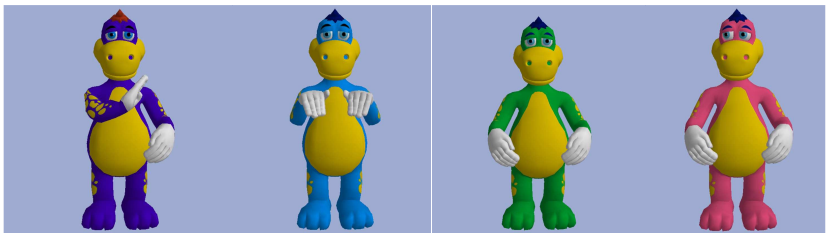

Figure 6: Several colour designs, reflecting the respective Zandkasteel characters

3.3.3 Screen construction and avatar positioning

The expert panel suggested using a “traditional” layout for presenting the signing avatar, similar to what’s used on TV with human signers: the video content on the

left with the signing avatar positioned on the right. The video content was projected onto a slightly skewed canvas by request of the experts, and we did not further investigate whether this was a necessity or that this was preferred as people were accustomed to this layout.
The size of the avatar was also considered important: it should be relatively large compared to the video. Because sign languages use the top part of a human body as signing space, the legs were discarded.

3.4 Results

The creation of the PoC was an iterative process, where intermediate results were created and evaluated. This was a necessity due to the highly experimental nature of the PoC, where several novel ideas needed to be tested and reviewed before we could continue. Additionally the iterations where used to improve the readability of the signs and avatar. Topics that were addressed include:

- Sign adjustments.
- Avatar adjustments (including its colour, the torso of the dino, and the colour and size of the hands).
- Timing adjustments: synchronisation of rendered signs with respect to the video.
- Positioning of the avatar with respect to the video.

The workflow of the PoC is given in Figure 7.

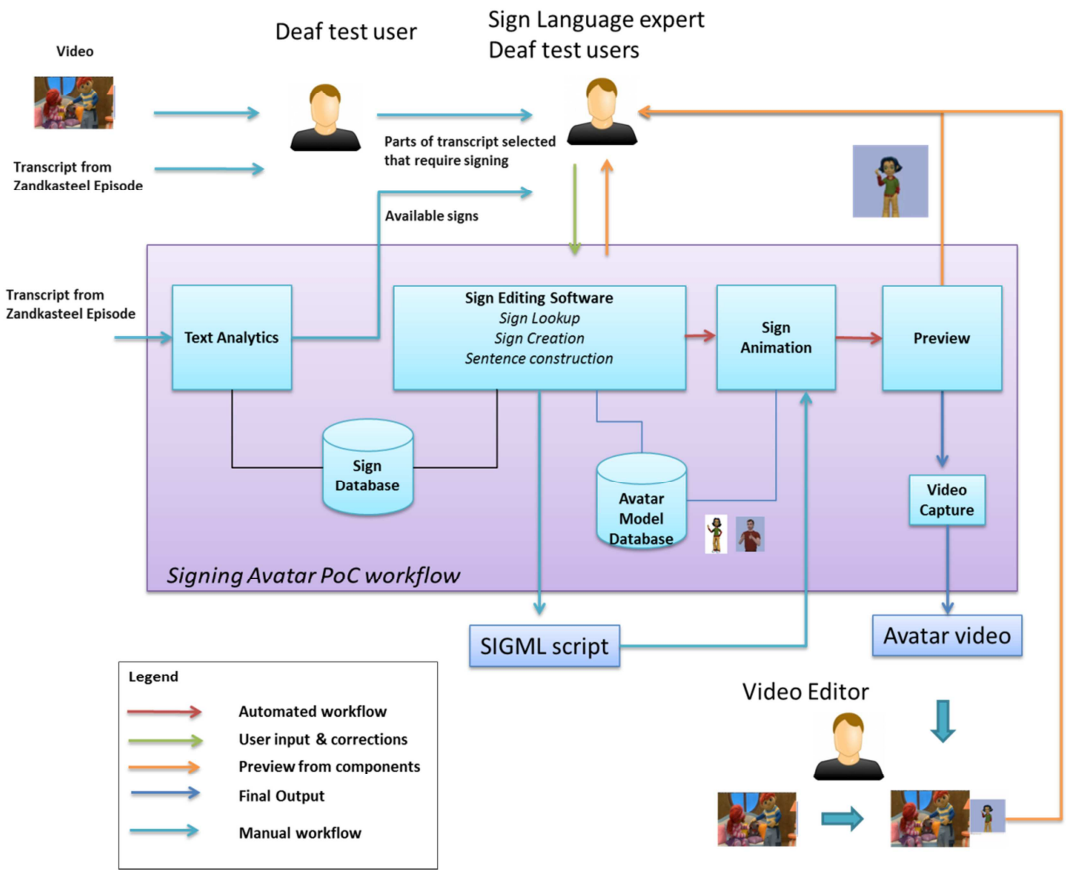

Figure 7: Workflow used in the Proof of Concept

3.5 Discussion

Throughout the process of creating the Proof-of-Concept several important observations were made, either by feedback by test viewers on any of the intermediate results, or through fruitful discussions with the experts involved in the project. The most important observations are:

- An avatar design could be reused by 're-skinning' e.g. changing the colours used for the skin of the avatar. This allows for easy repurposing of a generic avatar design for a TV show, or even many different TV shows. To avoid the uncanny valley effect, a human-looking avatar was replaced by a more cartoonish/animal like design. The expert panel feedback was positive about this change of character designs (although still had suggestions for improvements).
- The new avatar design had a different, more voluptuous body structure compared to the earlier human based designs. This caused problems with the rendering of some of the signs, such as collisions between hands and face end hands moving through the belly. This required some tweaking of the character design, but also (manual) corrections to a couple of signs that were suitable for the old avatars but not for the new models.
- Creation of new signs costs about 10 minutes of work for an experienced sign editor.
- Some signs may need to be re-edited multiple times until the sign-editor is satisfied with the result. This leads to an increase in the time it takes to create a sign (and consequently the time it takes to create the episode)
- While the manual components of a sign did not prove much of an issue, the non-manual parts did. The editors were constrained by the capabilities of the software to create (more) accurate facial expressions, mouth shapes and body movements.
- Timing of signs is really important, as a hearing impaired user will most likely use the avatar to retrieve additional information about what is happening on screen. A user however cannot focus on the video and the avatar at the same time. Therefore there needs to be some delay between a character saying something in the video and the avatar signing the same.
- The software that was used for the PoC was developed within academic research projects and therefore has different requirements from software that would be used in an operational settings. This specifically relates to technological readiness, support and sustainability of the software.
- Although avatar models can be exchanged, there is no guarantee that signs that are rendered correctly with one model, also render correctly with a new model, especially when body posture differs greatly from the human skeleton / human shape. For the evaluation, about ten signs needed to be adjusted to improve readability.

In an ideal scenario, a signing avatar service would consist of an automated workflow, in which a video with signing avatar would be automatically created using text (subtitles, a transcript, and closed captioning), audio (speech) and/or the video

itself to determine what needs to be signed to allow a complete understanding of the contents of the video.

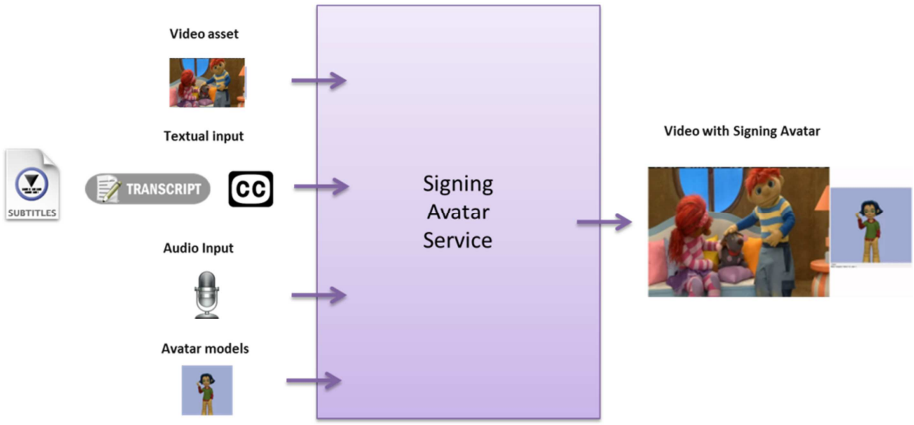

Figure 8: Fully automated signing avatar service (conceptual)

The feasibility study showed that a fully automated workflow would not be possible given the state of the art. Our feasibility study and subsequent work on the PoC has shown that the following research questions are still open:

- Translating a spoken language into a sign language. Note that a sign language is a language of its own, so this is comparable to the general translation problem. This also includes the process of disambiguation
- Determining and interpreting context of the audio-visual material to be able to establish which spoken concepts need to be signed.
- Detecting and tracking objects in the video, such that the avatar can effectively address (the location of) people or objects on screen. For the PoC this had to be done manually. Integrating the various components.

These are hard problems to tackle, and we estimate that it will take at least another 5 years before a fully automated system can be built that is ready for prime time – and possibly more.

4 User evaluation

The effectiveness of a signing avatar can best be evaluated in practise by allowing children with a hearing impairment to provide feedback. The impairment varies per person and can consist of *Deafness* (Dutch: Doof/D) or *Hard of hearing* (Dutch: Slechthorend/SH). For people with a hearing impairment, understanding a television program without support is a challenge. In this user study was executed to evaluate the added value of a signing avatar for the proposed target population.

This leads to the main research question for this study:

RQ1 *What is the effect of adding a signing avatar to a children's television show on the viewing experience of children with a hearing impairment?*

The main research question is split into multiple specific questions.

RQ1.1 *Are the signs of the avatar recognised and understood by the children?*
RQ1.2 *How do the children value the avatar?*
RQ1.3 *How does an avatar contribute to the understanding of the episode?*

The next section describes the design of the executed user study.

4.1 Method

In order to answer the research questions, the following experiment was conducted.

4.1.1 Participants

The participant population for this research consisted of 16 children (8 male - 8 female, average age 7.4 years [sd = 0,7]) with a hearing impairment. The children were recruited from two classes (group 3/4 SH and group 3/4 D) of the M. Polanoschool in Rotterdam (NL). This school specialises in education for children with a hearing impairment. The children in this experiment were a little older compared to the target population of the series, in order to receive valuable feedback. Next to the children, the teachers of the classes and a sign-language expert from Radboud University (Nijmegen, NL) were present during the experiment sessions. The school has an overall agreement with the parents for children's participation in scientific research. In addition the parents received a letter explaining the procedure and allowing them to withdraw their child from the experiment. After the experiment was completed, the children received a stuffed toy in the shape of a *Zandkasteel* character for their participation.

4.1.2 Material

For the User evaluation we created a modified version of the *"Finnie is Lief"* (Sweet Finnie) episode of Dutch television program *"Het Zandkasteel"* (The sand castle). Produced by NTR (broadcaster) and aired by NPO (Dutch Public Service Television)
The program usually contains a number of intermezzos without characters; these were all skipped. A name sign part was added before the episode, in which the avatar introduces the characters of the episode.

The final version consisted of 9:53 (mm:ss) of video material with audio.

A sign language interpreter was present to interpret between the children and the experiment leader.

4.1.2.1 Measures

Video cameras were used to record the experiments. The footage was only collected for scientific data collection purposes.

A comprehension and interpretation questionnaire was used to assess the level of comprehension of the signs as displayed by the avatar. In total 21 signs (and one practice sign) were selected from the episode taking the difficulty (both easy & difficult) and word category (verb, noun, etc.) into account (see Appendix A). Given the age of the children, questions were asked verbally/signed and children could answer by ticking one of the answer pictures.

Figure 9: Example of answer options for a question on characters. The sixth option could be picked if the child, had no clue.

The questionnaire consisted of three parts. The first part were 21 sign comprehension questions (and one practise exercise). The second part contained five interpretation questions. The third part consisted of one 7-point-Likert-scale with smileys to rate the episode with avatar.

Observation forms The adults present (hearing and deaf, able and unable to use sign language) were given an observation form to write down their perception of the viewing experience of the children, and their own pros and cons of the proposed avatar.

4.1.2.2 Setup

The setup for the experiments was built in the children's own classroom. Two different configurations of seats and desks were used during the experiment: "Group position", in which they were close together and close to the screen, and "Individual position", in which the children could not easily copy their neighbour's answers..

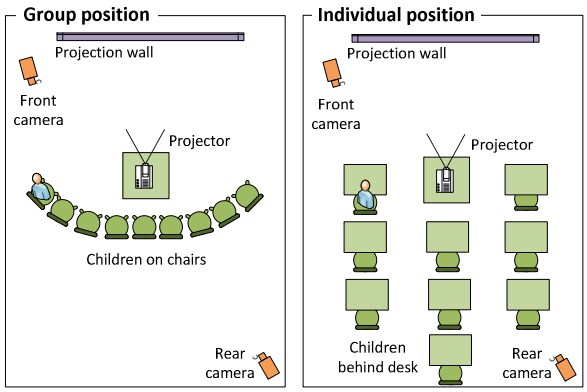

Figure 10: Two different classroom configurations: Group position & Individual position.

4.1.3 Design

The experimental design of this study contained one condition in which the children viewed the episode with signing avatar. Various dependent variables were used to collect the data, including questionnaires for the children, observation forms for the teachers, video files for remarks & non-verbal responses of the participants.

4.1.4 Procedure

The procedure for the classroom experiments consisted of two blocks in time.

Block 1 (30 minutes): First the adults in the room were introduced, followed by the purpose of the experiment, an explanation of the video cameras present, and a verbal consent by the children (1: do you understand the procedure? / 2: do you have any questions? / 3: shall we start?).

The experimenter introduced the signing avatar to the children. Afterwards the avatar and episode were shortly introduced by a sign language expert on a video (44 seconds).

The avatar showed individual signs twice in a row with a pause in between. The children were placed in Individual position (see setup). Questionnaires were handed out on which they could pick the corresponding picture out of five options for each sign. If they did not know the answer, they could pick the question mark option (option 6). First the experimenter practised one easy exercise together with the group (‘to drink’).

A short break (10-15 minutes) allowed the children to relax and prepare to focus in the next block again.

Block 2 (30 minutes): The second block started by the video playback of the episode with signing avatar and audio in Group position.

Afterwards the children went back to Individual position to answer the five complex questions. For each question we showed a short (less than 15 second) fragment of the episode without sound. The experimenter asked a question (e.g. Where do they want to play?). Answers were given individually on paper. Afterwards they filled out the smiley scale and the answer sheets were handed in.

The sign-language researcher then asked the children a few questions about their perception of the avatar.

The children and teachers were thanked for their participation by handing out the gifts and a group picture was taken.

4.2 Results

The classroom experiments took place on Wednesday morning March 12th 2014 in Rotterdam. As first class 3/4 SH was visited, followed by 3/4 D.

Figure 11: Overview of collaboratively reviewing the signs (experiment leader standing, interpreter sitting on the right hand side of the screen).

4.2.1 Comprehension questions

Children picked the answer picture that matched the sign presented by the avatar. Out of the 336 items (21 signs for each 16 participants), 4 questions were not answered (PP01) and 44 question marks (‘?’) were picked.

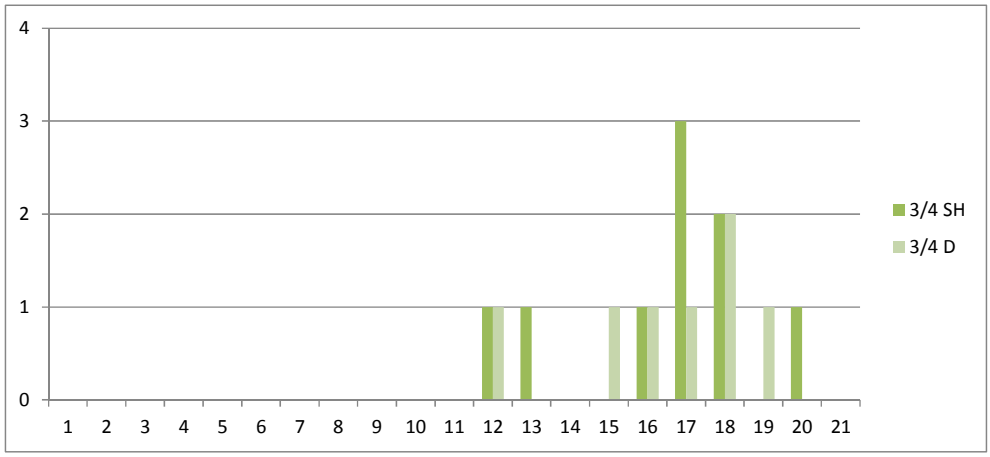

Figure 12: Histogram of the number of correct answers per class (both averages 16.4 correct answers). Example: 3 children in 3/4 SH answered 17 questions correct.

Both classes showed similar recognition rates (16.4 answers correct for both 3/4 SH and 3/4 D). Looking at the individual items large differences appear. The data shows that some signs were recognised by all children: Mand ("Basket") , Finnie (character), Strelen ("to caress") , Drinken ("to drink"). Others were recognised the least frequently: Brokjes (dog food chunks), Geven ("to give") and Rustig (quiet, calm)).

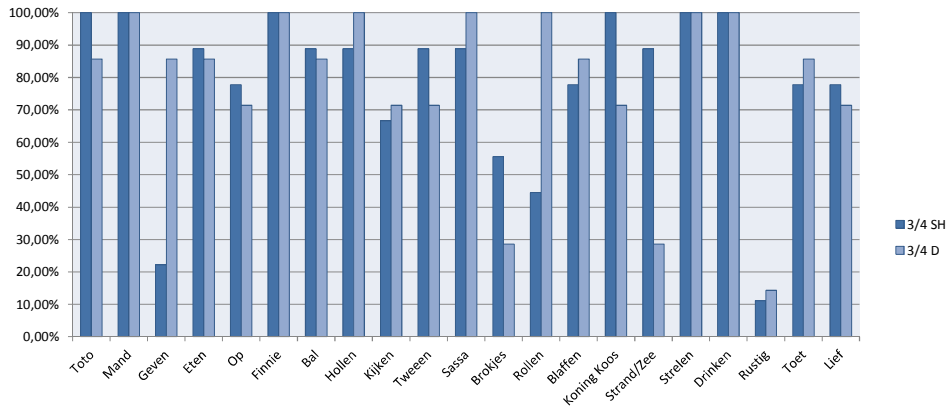

Figure 13: Percentage of correct answers per item split by class. Example: Hollen ("to run") was answered correct by all children in 3/4 D, and by 89% in 3/4 SH.

4.2.2 *Observations during episode*

Children in both classes were focussed while viewing the episode. They laughed sometimes and looked at each other for a short period of time. Some participants also mimicked signs during the episode. After the episode, four children waved to the characters to say goodbye. We list some quotes and observations.

PP08 immediately recognised the avatar changing colour: "Ha, de kleur verandert!-smile" ("Hey, the colour's changing" – followed by a smile).

Class 3/4SH answered together after the episode ended: "[Het is] echt leuk. Ik wil er nog een [zien]!" ("[It is] really fun! I would like [to see] another one!")

To the question where their focus was during the episode, some children indicated that they look first at the signs of the avatar, afterwards to the episode. Others indicated that they paid attention to both at the same time.

We asked the classes, could you follow the episode without the dino? (Als de dino weg was geweest hadden jullie het dan kunnen volgen?). All together they answered “No”.

Did the avatar use proper signs? (Gebruikte de dino goede gebaren?), PP14 answered: “Perfect!”.

Class 3/4D indicated that they understood the changing colours of the avatar: “If the person said something, [the dino] changed colour to the person speaking”. (“Als de persoon iets zij, praatte, dan veranderde [de dino] naar de kleur van de persoon die praatte”.)

The interpreter indicated that some children mention a preference for an improved viseme (mondbeeld), while others do not seem to care.

One of the researchers asked about the size of the avatar. PP11 answered “Hoeft niet kleiner of groter” (No need to increase or decrease the size).

Figure 14: Children waving to the characters / avatar.

4.2.3 Observations by adults

These results summarize the remarks on the observation forms (5 forms handed in) and the remarks given afterwards at the group discussion with the teachers (5 teachers from the classes, one expert from Radboud University).

Viewing behaviour. Observers report that children look interested, enthusiastic and relaxed. One of the observers describes that “Sometimes they laugh at funny parts of the episode (gives me the feeling that they understand the story).”

Positive aspects

- Signs of the avatar are clear
- Avatar uses different colours to indicate which character it is interpreting
- The avatar has a calm appearance
- The avatar does not sign too fast

- The avatar is correctly placed next to the viewing canvas (Right hand side of the screen)

Aspects to improve

- Visemes (‘mondbeeld’- mouth image) do not always match phonemes (e.g. finished/Dutch:‘Op-Op’ is shown while the character states ‘op-per-de-pop’). If the viseme is totally off, it might be better to leave it out.
- Role play (change of colours) is not always clear
- The moment a song is played the avatar does not indicate this change of setting.

4.2.4 Interpretation questions

All children answered the five interpretation questions that were fragments of the episode. Since all questions could be answered by picking one of five answers, the chance level is 20%.

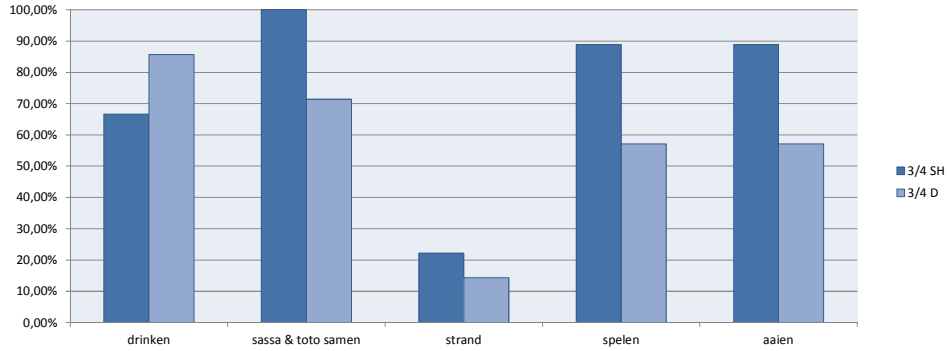

Figure 15: Percentage of correct answers per question split by class.

4.3 Conclusion and discussion

Based on the results presented, we draw conclusions to the research questions posed earlier on in this chapter. Further on, we discuss the results.

4.3.1 Conclusion

Children, teachers and experts show a positive response to the concept of adding a signing avatar to an episode of a children’s TV program. The user study at school shows that on average 16.4 out of 21 signs were correctly recognised by 16 participating children. Based on the comments by the children, the observed behaviour and the smiley scale, we see the appreciation for adding the avatar to the episode. Interpretation questions show an above chance response which suggests a positive influence on the understanding. However, due to the limited amount of data, we cannot draw firm conclusions on the overall understanding of the episode.

4.3.2 Discussion

The user study shows positive responses by the target population on this first prototype. The participants involved recognise the added value for an avatar in children’s programs and provided valuable feedback for improvements.

Most of the interpretation questions were answered correctly by the children. With respect to question 12 that were answered correctly by 44%, the sign (in hindsight) could be interpreted in many ways and might be improved (e.g. brokjes / dry food for dogs). In this case the context of the sign played an important role: the teachers indicated that the children had learned another sign for “brokjes”.

Some answer categories could be improved by picking better matching pictures (Rustig, “Quiet”). The interpretation questions (K1-K5) appeared difficult to understand for the children. The phrasing of the questions could be improved, and possibly the moment of asking (concentration was lower after 45 minutes).

The episode contains a couple of songs. It is common for an interpreter to indicate that a song is playing. Suggestions to improve this, would be a wiggling avatar during the song or showing musical notes.

In the execution of some signs the motion of the mouth did not match the word. We suggest to investigate this technical issue in depth or leave out the viseme in case the mouth motion is totally off. This is preferred by the teachers over an incorrect viseme.

This user study shows great potential for adding a signing avatar to children’s programs. We note that only limited material (one episode) was used to perform the user study. It would be interesting to investigate the long-term effects of such an avatar on the target population. What would be the learning curve in viewing behaviour? And how would this influence the understanding and appreciation of these programs in the future?

5 Conclusion

5.1 Conclusion

The Proof of Concept and user evaluation show that a signing avatar has added value for the experience of a TV-program by deaf and hearing impaired children.

The user evaluation shows that the children involved have a good understanding of the signs that were presented by the avatar and, to some extent, were able to correctly interpret the information signed the signing avatar, information which would not be comprehensible by just looking at the video (without audio). This outcome is remarkably positive, given the constraints of the technology that has been used, specifically the limitations of (fluently) rendering body motions and facial expressions (an essential part of sign languages).

Given the constraints of the technology that has been used, specifically the limitations of (fluently) rendering body motions and facial expressions (an essential part of sign languages), this is a really positive outcome.

We identified that not all information that is written in a script needs to be communicated by a signing avatar. A lot of information is already communicated via the video; only the parts of information that are communicated via sound need to be signed. This means that, whilst we were unable to use NGT as a basis for the signing avatar, we were able to render signs in a NmG-like fashion, which the children could understand.

The dino-based avatar that was used in the evaluation brought many improvements over the human-like avatars, even when the constraints of the underlying technology were not be resolved.

The user evaluation shows that a single avatar model can be used to support the different roles (characters; narrator) in a TV-program, by only changing its layout (e.g. the colour scheme). By having a relatively neutral design an avatar can thus be customized to support different characters, and potentially many TV-programs.

The degree of apprehension of the signing avatar and thus exact degree to which a signing avatar is an added value is difficulty to state, as the user evaluation tests were performed with a limited amount of test content, and a limited number of test subjects. Drawing firm conclusions requires significantly more testing, with other content, more test users over a prolonged period of time.

An important observation that has to be made, is that all of the people that (directly or indirectly) contributed to the project, are positive about the final result: the Zandkasteel episode with signing avatars. Even while being critical about the end-result (leading in numerous suggestions for improvements) the overall reaction is: this is something worth doing and benefits hearing impaired children, even when many significant improvements need to be made.

With respect to the PoC implementation, we make the following observations:

- The tools used for the PoC that were developed in an academic setting, have different requirements regarding support, reliability and features compared to an operational setting (a broadcaster). We identified some problems when using the software.
- The signing tools that were used require specialized training. Currently a limited number of users are able to operate the software (3 in the Netherlands); in an operational solution, we would recommend that more people would be able to operate the software, and that the software would be much easier to operate.
- Several iterations and significant efforts were needed to create an episode of Zandkasteel with a signing avatar, which was suitable for user evaluation. Each iteration built upon the previous one, improving aspects like: sign correction, avatar timing, avatar design, avatar colour usage, screen layout, etc.

5.2 Discussion

The amount of manual labour and specific knowledge that was required to create the Proof Of Concept, show us that realizing a fully automated workflow is not likely in the short term. This requires significant developments in a number of areas. A rough estimate before being able to provide a mostly automated workflow is at least 5 years.

Considering the size of the target audience[19] the investments to be made to create an fully operational solution, will probably be too high at a national level.

Many of the challenges we identified however are irrespective of the (sign) language being used. We therefore recommend the NPO to continue its efforts in a European context, as we think that the challenges identified are relevant to other countries as well: text and video analytics, sign composition, avatar rendering solutions, etc.
By addressing these issues on a European level instead of a national level, the economics of scale may increase technological developments, and thus reduce time and investments for an operational solution.

For this project we made use of earlier developments in European research projects and in this project we worked with several international parties as well.
We believe that this is a good way to proceed for creating an avatar based signing service. A possible consideration for NPO is the Horizon 2020 European framework for Research and Innovation[20], which might provide opportunities for establishing an European based effort for signing avatar services.

5.3 Future work

Throughout the feasibility study, the creation of the Proof of Concept, and finally the user evaluation, we identified several key areas with technical challenges. Improvements in any of the fields will benefit the creation of avatar based signing services:

[19] The actual number of hearing impaired people in the Netherlands is unknown. Predication vary between 24.000~33.000 hearing impaired, with an outlier of 1400000 with a hearing disorder. Additionally relatives of hearing impaired people may also benefit to additional exposure to sign language.
[20] Horizon 2020 website: http://ec.europa.eu/programmes/horizon2020/

1. **Language translation & interpretation**
   Translation between a spoken language (such as Dutch) and Sign language (such as NGT) is a technical complex problem. It will be worthwhile to further investigate to what extend this translation problem can be resolved, especially with respect to interpreting the context of what is being spoken.

2. **Avatar rendering**
   Signing avatar software may be extended to address an issues that was raised many times in this project: the shortcomings of the non-manual gesture rendering. Especially the support of facial expressions and mouth movements could be improved. Additionally body movements could be improved.

3. **Signing avatar service workflow**
   In the Proof-of-Concept several standalone tools were used to create the signing avatar for Zandkasteel. Some of the tools were entirely operated by hand, while others could be operated automatically. Several questions remain:
   - How can an (semi)automated workflow be created, such that it can be supported in a broadcaster's operational environment?
   - How can tools that were created for research purposes repurposed for operational purposes, with additional requirements with respect to support, maturity and reliability?

4. **Extended user testing**
   Additional user tests can be used to get a better understanding of what parts of the signing based avatar service need to be improved, and additionally, to gain insights in determining what information needs to be signed. It is recommended to create more content for testing purposes. To increase test exposure, the broadcaster could make use of HbbTV as a method to distribute content with signing avatars to test users. As an example, tests with accessibility services via HbbTV is already being done in the Hbb4All[21] European research project. NPO might want to contribute to this or similar projects.

[21] http://www.hbb4all.eu/

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We would like to express our appreciation and gratitude to a number of people whose help has been instrumental to carrying out this research, in no particular order:

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- Ivan Orvieto (Testaluna)
- Neeltje van de Bedem (Universiteit Leiden)
- Daan Hermans, Ben Elsendoorn (Kentalis Nederland)

A List of signs

vb	Drinken	To drink
1	Toto	Toto (character)
2	Mand	Basket
3	Geven	To give
4	Eten	To eat
5	Op	Tired / exhausted or finished (as in finishing all the food)
6	Finnie	Finnie (character)
7	Bal	Ball
8	Hollen	To run
9	Kijken	To look, to see
10	Tweeën	Two of us/them
11	Sassa	Sassa (character)
12	Brokjes	Chunks (dog food)
13	Rollen	To roll
14	Blaffen	To bark
15	Koning Koos	Koning Koos (character)
16	Strand/Zee	Beach
17	Strelen	To pet
18	Drinken	To drink
19	Rustig	Quiet, calm
20	Toet	Toet (character)
21	Lief	Sweet, nice