Portable, Affordable and Smart Communication Aids for Children With Speech Disabilities

***Abstract*—Millions of children with severe speech disorders are in need of affordable, portable and effective communication aids. To address this, an Android application has been developed where the user expresses phrases as a sequence of pictograms, which are "translated" into natural language and spoken through a speech synthesizer. The application takes care of certain linguistic dependences resulting in higher degree of grammatic correctness. The application includes over 900 pictograms, supports French and English and is open-source.**

To cover the needs of people with speech disabilities, much research is still needed to make these devices less limiting, more effective and requiring less user's attention. For we review the recent developments in non-widespread approaches, which in some cases are already able to meet most of the earlier requirements.

***Index Terms*—Disability, Augmentative and Alternative Communication (AAC), Assistive technology, Communication symbols, Natural language generation, Portable computers, Speech synthesis.

I. Introduction

Throughout this paper our focus will be on a significant minority of children who are not able to use speech as their primary means of communication. It has been estimated that around 0.3% to 0.6% of the total school population fall into this category, while similar numbers hold for preschoolers [4, p. 200]. In such cases, communication can still be established by employing *Augmentative and Alternative Communication* (AAC) which is "any method that supplements or replaces speech and writing when these are temporarily or permanently impaired and inadequate to meet all or some of a person's communication needs"[17, p.1].

The AAC methods are classified into those that do not require any external tool (Unaided AAC) (e.g. gestures, facial expressions, mime, pointing, eye movement, low-intelligibility speech and manual-signs (MS) of some sign language); and others that require some external device (Aided AAC), including Picture-Exchange (*PE*) by pointing or exchanging pictograms and many kinds of Speech Generating Devices (SGD) [3], [7] of which the most common are based on pictograms (whereas other types are based on keyboards, eye-tracking devices, joysticks, brain-interfacing, etc).

The choice of the best method(s) depends on child's personal preferences and any other disorder that may be present such as motor impairments or developmental difficulties. Most of the children assessed to date "appear to show a preference for using the *SGD* over *PE* and *MS*"[19, p.463]. Meer et al.[19] also found that children with developmental disabilities can learn to use *PE* and *SGD* more easily than manual-signing (MS)[1]. Hereafter, we only consider children with sufficient motoric abilities to use a Speech Generating Device (SGD).

A. Our motivation

To our knowledge, there is no lightweight low priced speech-generating *AAC* device that provides a child with the ability to easily express phrases *in French*, without being limited to only very low number of predefined phrases[2] (this is also true for many other languages at least to some extent).

Therefore, millions of children worldwide are in need of affordable communication aids of an acceptable quality to both ease and stimulate their communication. Lack of such aids could have a negative impact on their mental development.

Further, French language having fairly complex grammar (e.g. conjugation, inflection according to number and grammatical gender) exposes an opportunity of shifting these linguistic tasks to a computer, which would result in a simpler user interface.

B. Human languages

"When used as a general concept, "language" refers to the cognitive faculty that enables humans to learn and use systems of complex communication"[19, p. 2]. Human (or natural) languages are usually spoken, written and governed by grammar. Beyond the almost unlimited expressiveness of a natural language, we may consider it as "a formal system of symbols governed by grammatical rules combining particular signs with particular meanings"[19, p. 2].

In addition to standard ways of expressing these symbols as words, sounds or logograms, one may consider the language of *Pictographic Symbols*, each with it's own meaning (in our implementation, represented as a word or a phrase) and governed by grammar that defines the sequence of these symbols (e.g. subject–verb–object order, as occurring in French and English). The task of our system is then translation from the language of pictograms into a natural (human) language.

C. Our work

In collaboration with the family of a child with speech disorders and on advise of AAC specialists from "Aragonese Portal of Augmentative and Alternative Communication"[3], we developed an application for Android tablets and smart-phones (that are lightweight, affordable and have sufficient processing power) which allows the user to express sentences by selecting

[1]This could be explained by the fact that "PE and SGD are less demanding on children's working memory because only recognition memory is needed, whereas MS requires the use of recall memory" [19, p.463]

[2]Costs start at US$ 100 for very simple devices; the more comprehensive ones weigh several kilograms and cost thousands of dollars (as much as US$ 16,000 [14, p. 30]) while the others cannot process French and many other languages (e.g. Serbian, Lithuanian, Russian) at all.

[3]http://arasaac.org/

pictograms and to recite the generated text through a speech synthesizer. The pictograms are treated not as individual words but as a sequence, benefiting from linguistic features such as standard word order in the given language and enabling the application to generate grammatically correct sentences by applying linguistic features (inflection, tenses, gender, number agreement) to dependent words automatically. Our innovation is that we take slightly different approach to mapping pictograms into text, that allows easily integrating existing natural language generation systems.

This also makes the application attractive in the completely different context of learning a foreign language interactively through composing pictogram sequences (i.e. the pictograms are fairly intuitive, while the generated text and speech convey the spelling rules, the grammar and the pronunciation of a language to be learned).

II. Problem definition

Our target audience is children who do not yet know how to spell words, but who may be able to identify the first letter(s). As the input method has to be intuitive to be easily adopted, basing it on pictograms in some way seems like a good option at least for children. Most other approaches are also based on pictograms. We want to minimize the pictographic input, while still generating grammatically correct language as close to natural speech as possible.

After the initial research, we stuck to representing words as pictograms and we wanted to make use of language features such as *natural word order* in the language (e.g. subject-verb-object) to improve the input performance. Based on that, we define the problem as converting a sequence of pictograms into sentence(s) of natural language.

III. The solution

Given a sequence of pictograms, we first map this into a *sentence tree* from which text is generated by employing a Natural Language Generation (NLG) toolkit. The resulting text is finally read aloud by a Text-To-Speech (TTS) engine.

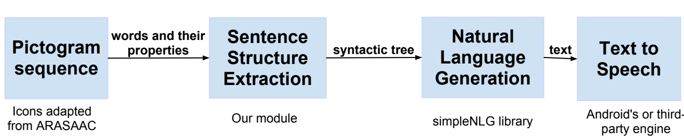


Figure 1. Processing flow: from pictograms into speech

For implementation, the *Android* platform has been chosen because of its higher customizability, compared with that of the *iPhone,* and this could even evolve into an input-method for other applications. We extended the existing *NLG* system *simpleNLG[6]*[4] which is capable of dealing with fairly complex French lexical and syntactic features, including tenses, inflection, gender, specific word-order etc. Our main task is therefore to map the list of pictograms into a syntactic structure (represented as a tree of dependent objects) to be fed to a NLG system.

A. Linguistic processing

Because a simplified subset of the French language may be considered as Context Free Grammar (*CFG*, defined below)[15] the problem of mapping a list of pictograms into a syntactic structure can be solved similarly to parsing a CFG. To make the development easier, less error-prone, and to ease the change management, *Unit tests* (mainly input and output pairs) have been heavily applied throughout the development of the code that carries out the linguistic processing.

Context Free Grammars: A grammar specifies the allowed syntactic constructions for a specific language and could be used to parse a given sentence into its syntactic tree. Grammars are usually defined in a recursive way in terms of *rewrite rules* that specify how more complex syntactic constituents (called *nonterminals* V) could be built from a string w consisting of smaller units: *nonterminals* (phrases) and/or *terminals* (words or word elements). A *Context-Free-Grammar (CFG)* is a grammar where these *rewrite rules (*in the format of $V \rightarrow w$*)* can be applied regardless of the context of a nonterminal V on the left side, while the right side may be composed of terminals or nonterminals. For example the rule below, taken from Fig.3, where the right side is expressed in terms of regular expression, defines that a clause can consist of a subject, optionally a modal, a verb, and any number of objects. In Fig. 3**,** the *subject* is defined as Noun phrase coordinate, while the *object* is a combination of NP+, Adv, Adj, or PP.

$$Clause \mapsto subject\; modal?\; verb\; object*$$

Despite their limits, the CFGs are still widely applied in linguistics because of their simplicity (while in *Stochastic CFG*s the rewrite rules are extended with their probabilities)[10].

Mapping sequence of pictograms into a syntactic tree: Based on[15], [20], and our notes on French grammar*,* a simple Context Free Grammar that covers the most important cases of French was defined (see Figure 3) and served as the basis for the implementation.

We created a simple "greedy" algorithm (see Alg. 1) to parse the sequence of pictograms . We prefer this to existing parsing algorithms because of simplicity and higher flexibility. First, the part-of-speech tags already exist in the input (each pictogram has simplified part-of-speech tags associated to it), thus this would result in lower complexity. Second, the resulting syntactic tree has to be a specific "object" structure fed into the existing natural language generation library with its own constraints. In addition, we wanted more flexibility for defining the input grammar.

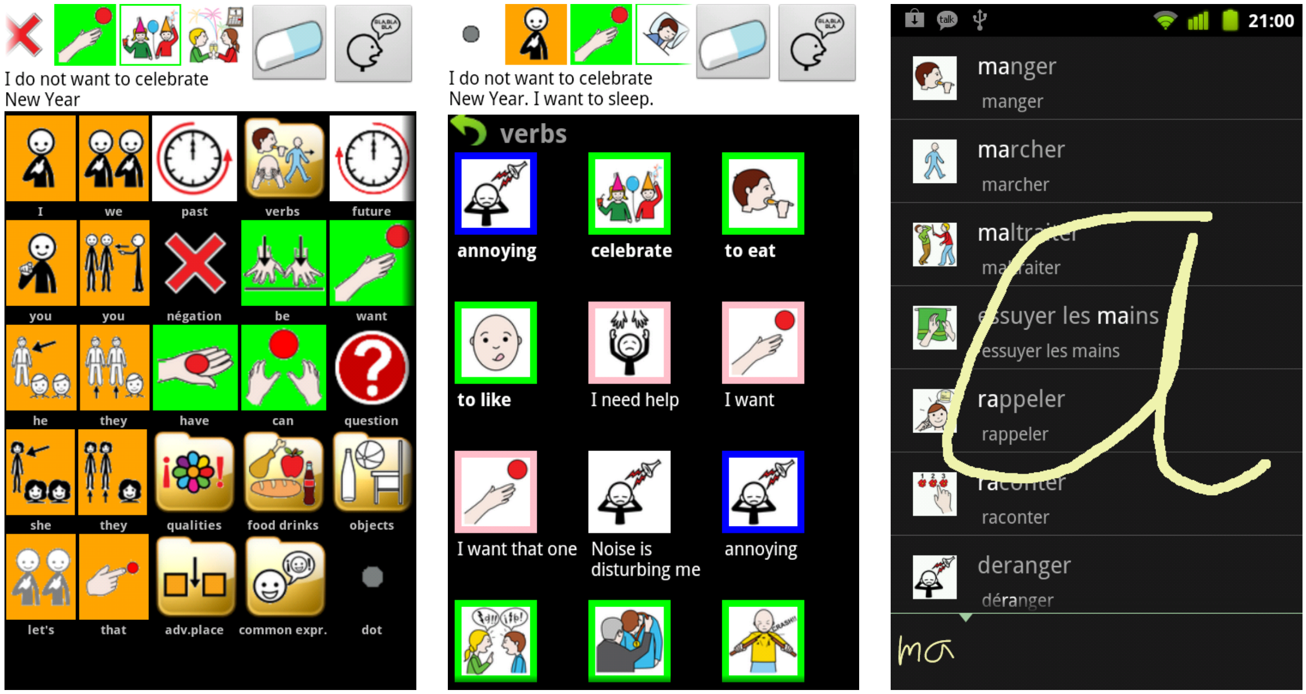
To illustrate its basics, consider this simple input in French (for more complex cases see Algorithm 1):

```
Input:N:Maman N:grand-père V:manger N:cerises Adj:sucré[5]
Output: Maman et grand-père mangent des cerises sucrées[6]
```

[4]There is also an English version of the *simpleNLG* library. We implemented a slightly more limited English version as well. There was some work on the German version, but the code has not been published (mainly because of issues with licensing of the lexical resources used)

[5]Translation: N:Mother N:grandfather V:to-eat N:cherries adj:sweet

[6]Translation: Mother and grandfather eat [in the correct form] [of] cherries sweet [in plural feminine]



a) Home screen b) Category view (most used items on top) c) Gesture search within category

Figure 2. Application screen shots on mobile phone

NP = adj* Nuon adj*
PP = prep NP?
Subject = NP+
Object = NP* | adv* | adj* | PP
Clause = subject modal? verb object*
Sentence = (clause [.?!])+

definitions:
NP – noun phrase
PP – preposition phrase
adv – adverb
adj – adjective
prep – preposition
multiplicity markers:
* = 0..inf ; + = 1..inf

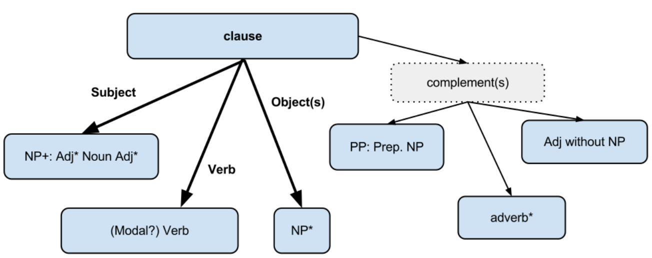


Figure 3. A Context-Free-Grammar for simplified French

The algorithm first matches as many Noun Phrases (NP) in a row into a Coordinated Noun Phrase (NP+) which is assigned as the subject. Then as there is only one verb, it becomes the Verb (V) of the clause. Everything that follows shall constitute the object, thus we match the subsequent Noun, *cerises*, and the Adjective (Adj) modifying it into a Noun Phrase (NP) that is set as the object of the clause. As we automatically add a preposition *de*, the last noun phrase now in fact belongs to a preposition phrase (PP) and because of the way simpleNLG works this now has to be presented as a complement of the clause. Notice that gender and number agreement is set automatically: 'cerises' is plural feminine, thus the gender and number of the whole PP it belongs to is set to plural feminine. This results in the following syntactic tree:

```
subject: <NP+: <NP: Maman et NP:grand-père>>
verb: <V: mangent>
object:<PP:<Prep:des,NP:<N:cerises,Adj:sucrées>>>
```

Guessing prepositions (for NPs with no specifiers): Some verbs go with one preposition more often than with others (e.g. *manger* goes with *de*, while *aider* goes with *à* [11]). By guessing the most probable preposition based on the verb and what follows it, we eliminate an extra input step. Returning to the earlier example, when we see the verb *manger* (to eat) which often goes with the preposition *de* (of) and there is no preposition specified, we add it automatically. It is also possible to have a different parse e.g. in *'manger à la cantine'* (to eat at the canteen), however this is the less common indirect object which shall be specified implicitly.

B. User interface

The most interesting functionality can be seen in Figure 2.

The pictograms are split into categories (folders) by their semantic meaning or function. The main screen contains the most important words ('to be', 'to want', 'to have', and 'to be able to'), the icons (buttons) to open categories, as well as icons for tenses, and negation. To make it easier to identify the function of a pictogram each pictogram is marked with one of the six standard SPC[7] colors.

In addition to linguistic features, the application also provides a list of recent phrases, and each category lists its most used pictograms on top. In the settings, there is an option

[7]The six categories of the System of Pictographic Communication (SPC) are: action, noun, proper noun, adjectives and descriptions, social (references, greetings, apologies) and miscellaneous (prepositions, conjunctions, etc)

whether to display the text in capital letters, and the user may also specify his/her gender. Thus all first person phrases would be automatically adjusted to his/her gender.

Gesture Search: On mobile phones where the screen is small, the standard on-screen keyboard is not reliable enough for disabled people and also occupy large part of the screen. To address this, we enabled[8] the users to search for words by drawing the first few letters of the word, instead of typing them with the keyboard (see Figure 2.c). If this happens within a category of less than one hundred icons, it is quite efficient.

Compatibility with both Mobiles and Tablets: To make the support of both tablets and mobiles an easier task, and to be able to present the same content on both (all available categories do not fit on one screen of a mobile phone), we created a virtual screen space for smaller mobiles with the possibility of switching between the left (Fig.2a.1) or the right virtual displays just by swiping a finger along the horizontal axis of the screen.

C. Obtaining and processing the icon set

After evaluating the icon sets that could be obtained freely, we learned that the ARASAAC[9] was the most comprehensive, containing more than 5,000 pictograms with words in multiple languages. Nonetheless, the dataset had to be preprocessed (resize images; remove the image/word duplicates; transform the data model; add part-of-speech tags; improve categorizations). To make the application a fully-working communicator, the icon set is still in need of some manual work to improve categorizations and part-of-speech tags.

IV. Related work

A. Research closely related to our topic

Higginbotham et al.[8] present a recent overview of applications of Natural Language Processing in the field of Alternative and Augmentative Communication *(AAC)*. They discuss various types of keyboards (optimized layouts, ambiguous (e.g. T9) and scanning keyboards, on-screen keyboards, word prediction), and present how extraction of the context (discourse genre; topic; user's location) could be applied to improve the performance of an AAC device. They claim that *Speech recognition* can also be used to extract the context by processing the collocutor's speech which may be used for providing intelligent guesses for the responses. Finally, they mention that even for subjects with low-intelligibility, dysarthric speech - significant additional keystroke savings can be achieved by combining text input of the first letter with Automatic Speech Recognition of their low-quality speech.

Silva and Pereira[17] while focusing on an eyesight-controlled pictogram-based interface, proposed an approach to validate the syntactic accuracy of sentences, returning "a subset of available pictorial symbols, in such a way that information is understandable and meaningful". We are use natural language generation which in addition allows the generation of text (and speech) with basic syntactic and lexical features applied automatically (tenses, gender, number, etc).

In the context of French language, Bellengier et al.[2] explored mapping of sequences of pictograms into text. They used transformation-rules, that iteratively transforms a word sequence into a sentence by applying linguistic features such as number agreement. Here, we have presented a different approach, that allows using existing *Natural Language Generation* systems cutting down the implementation costs (as there is no need to create module that does the language specific linguistic processing). Also, they have used reformulation rules allowing to entering certain types of sentences quicker by omitting articles, prepositions.

Abraham [1] stressed the importance of making it easy to find and identify the pictograms. First, it is important for the pictograms to be organized in intuitive (semantic) way, both into the categories and within them. As alphabetic order is not so useful then users do not know (or know just a little) how to write, within the categories, the icons could be organized into clusters according to their semantic proximity. Second, a good design of pictograms is important so that pictogram's meaning could be easily identified. Our prototype still needs lots of work in this direction.

It is that children are able to use pictogram order only up to a certain extent relevant to their age to extract and express the syntactic features they represent, with the youngest ones able to identify the simple structures (e.g. subject-verb, even if in spoken language they are able to identify more), and older ones more complex ones (e.g. subject-verb-complement)[18]. Therefore another important direction is designing aids to support learning in how to use the pictogram sets, for example, the Axelia pictogram set has prepared a booklet with illustrated stories that are also expressed in "pictogram language"[10].

B. More distant research topics

Non-invasive Electromyography (EMG): A non-invasive *EMG* sensor that captures the neurological signals being sent to the muscles can be placed near the vocal chords (larynx). Analysis of these signals could be used to heal stuttering through bio-feedback that helps to learn how to remove excessive tension in the muscles.

Another notable use-case is identifying the phonemes that allows the spelling of single letters, even with only one electrode placed near the larynx. This is non-invasive and *could be non-visible*, as the sensor near the larynx can be easily hidden by clothing[11]. For these signals to be recorded, it is not necessary for the muscles to move (in some diseases, it is only the muscle movements that are impaired, while the impulses may still exist). However, the performance is quite low.

Researchers from Germany[9] extended this by adding additional *EMG* electrodes (on the lower part of the jaw, near the nose and the sides of the lips) and, by applying sophisticated signal processing, obtained a silent speech interface for

[8] This was implemented by integrating Google's Gesture Search[12].

[9] Arasaac.org

[10] http://www.axelia.com/

[11] http://www.theaudeo.com/?action=technology was working on making these sensors comfortable to use

Algorithm 1 Pseudo-code of algorithm to transform pictogram sequence into a sentence-tree

```
# Matches Noun Phrase (NP) coordinate:
funtion Match NP Coordinate(next):
      NP_coord = Match as many of NPs in a row, but NP may only contain one noun + adjectives
      return  NP_coord

function starts_NP(next):
      return true if next is noun or adjectives with a noun afterwards

while there are unmatched pictograms:
      (next is always set to not yet matched pictogram (word) from left to right)
      # matches Subject or Object
      if not clause.subject and starts_NP(next):
            clause.subject = match first NP coordinate
      elsif starts_NP(next):
            clause.object = match all subsequent NP coordinates (if any):
            if there is no specifier:
                  try to guess the specifier (de, à) from the verb (e.g. je mange de glace)
      # matches preposition phrase
      if next is Preposition:
            PP = Preposition + match subsequent NP
            clause.addComplement(PP)
      # matches an Adverb as complement of a clause
      if next is Adverb:
            clause.addComplement(all adverbs matched in a row)
      # Adjective attached to the clause, not to noun; e.g. tu es joli
      if next is Adjective:
            clause.setComplement(adjective)
      if next is Verb:
            set the verb
            if more than one verb exists:
                  set first verb as modal, second as verb # e.g. je veux manger
      set tenses, negation and other features which are also represented as pictograms
```

continuous speech with impressive results - predicting words pronounced silently at normal pace with ~10% word-error-rate in a vocabulary of 2,000 words. The downsides are: a) the electrodes with their cables are unattractive and b) depending on actual disorders it might be harder for disabled people to control the signals sent to the muscles.

Vocal Aid for people after Laryngectomy: Applying signal processing to the microphone-recorded disturbed voice of people who have had a *Laryngectomy* (i.e. removed of the larynx) was shown to be successful [13], [16] in restoring the naturalness of the voice in comparison to other approaches such as the *Electric Larynx,* which gives a robotic and unstable sound. It would be an interesting research topic to check if use of EMG sensors near the muscles of the larynx or the tongue could improve these results.

Brain-Computer interfaces (BCI): Because of low input rates of non-invasive BCIs, they are currently selected only when other options are not available (e.g. in the case of severe motor disability). On the other hand, recent advances in BCI technology are quite promising: for instance, Emotiv EPOC, a 300$ consumer BCI, is able to recognize motion-related thoughts such as *turning left or right, going up or down, disappearance* and facial expressions (through EMG). Being intended for gaming, it could also be used to control a wheel-chair, home-appliances etc.

Other approaches: one hand keyboards[12]: could be a favorable option for the people with good motor abilities (flexible input, high input rates, one hand free, no need to look at the screen); *Swype*[13]: the user just swipes his finger through the on-screen-keyboard without need to click on individual letters. This could be very successful with users capable of writing and having good motoric skills; *Sensor Gloves and/or Video capturing*: could be used to translate from sign languages into natural language[5]

V. Future work

As the application presented was developed during a short semester-project, there is still much work to be done to improve the application .

First the icon set has to be better tagged (this needs manual work). Further, organizing the icon set in semantic way would make locating items easier. Then the ability of the users to add their own icons/photos associated with phrases is a highly requested feature.

It is worth looking into predicting the next most possible icons given partial input that could be useful for frequent phrases, e.g. I want <to eat; to sleep>; I like <this; you; swimming> etc) which could be implemented by evaluating conditional word probabilities. It is also possible to make the application available in other applications as *Android's* input method, e.g. for typing an SMS, or even as voice input for making phone calls.

Usage of context could be researched, e.g.: a) the system could behave differently depending on location b) speech recognition could be beneficial at least in some cases: e.g. if asked: "Did you like this?", the application could propose the most feasible answers: "Yes, a lot", "Not at all".

[12] e.g. http://handykey.com is a portable fully featured (all computer keys available) one hand 18 button keypad+mouse, which is supposed to relieve the repetitive strain injury with reported rates of 30-60 words/min; http://keyglove.net open source prototype of 200$ keyglove with many finger states

[13] http://swype.com/. Based on the curves drawn with the finger, the application computes the best statistical matches of words including error correction. It has been claimed that an experienced user could achieve 300 symbols per minute, which is a lot for mobile device. Indeed, from the author's experience, it works very well for English language, and fairly well for French.

Lastly we could investigate more advanced linguistic processing (at the semantic or even pragmatic levels), allowing the pictograms to have slightly different semantic interpretations depending on the context (e.g. meaning of other pictograms nearby, recent phrase history).

All these shall be followed by quantitative measurements evaluating the performance of the system and impact of changes to the speech rate, flexibility etc that had to be left-out because of the scope of semester project.

VI. Conclusions

We have presented a mobile application helping children with speech disabilities to communicate by "translating" pictograms into speech and automatically taking care of linguistic features such as inflection, tenses, gender and number agreement. A novel approach to mapping pictograms into text which allows easy integration with existing natural language generation systems, and a prototype of a different way of searching by the first few letters by drawing them of the screen, was presented.

The solution applies to adults too, but it benefits children the most, who (being not yet able to spell or even read) have much fewer alternatives than the adults (e.g. highly performing options such as T9, Swype and one-hand keyboards).

Even if the application is still at the early stage of a working prototype[14], within nine months of releasing the early prototype we obtained more installations and feedback than expected[15]. The feedback shows that a) users find our linguistic approach particularly interesting and b) there is clearly a lack of affordable portable communication aids of sufficient quality.

We have released our application as an open-source - hoping to participate in filling the availability gap - at least for the French speakers. Unfortunately, it seems the open-source community for Alternative and Augmentative Communication (AAC) is not as active as in other fields. On the other hand, the author has received a request for using his code and collaborating in building an AAC communicator for the Serbian language by a non-profit project sponsored by the Serbian Government[16].

Finally, despite many years of research serious problems exist with most AAC systems: they either limit the user's movement and expressibility, require his/her significant attention and have fairly low input rates. All of these issues discourage users from using these devices even if they have no better choice. This seems to be supported by the feedback received from our first user, who avoids using any AAC tool unless it is really needed (e.g. she is able to express herself to some extent with gestures, facial expressions, and low-intelligibility speech at home). While there is some potential to improve existing methods, it is worthwhile to invest in the development of not-yet-mature/non-windespread alternatives that could provide less limiting interfaces (e.g. Brain-interfacing, Electromyography, Sign-Gloves).

[14]as implemented by one student during a part-time (one) semester project

[15]Being published on *https://play.google.com/* and the App. store for the *Nabi Platform* http://www.nabitablet.com/, without using any particular advertisement, we have currently achieved more than 1,700 active installations and more than 4,000 downloads. It is however hard to estimate the actual day to day usage, but we have received a dozen of emails with feedback.

[16]The project would additionally include linguistic work in building and integrating a Natural Language Processing engine for the Serbian language, as the engine currently used only supports English and French.

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