

Semantic Knowledge-based Language Education Device for Children with Developmental Disabilities

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Abstract—Autism spectrum disorder (ASD) is one of the most significant public health concerns in the United States and also worldwide. Children with ASD or other developmental disabilities (DD) are often lacking in verbal ability. Even though early interventions can improve it greatly, access to special education services are often challenging for families with a child with DD. This research study proposed a cyber-physical system that can be easily deployed in a daily environment of children with DD and can teach them language. As a part of this ultimate goal, this research project explored how semantic technology can be applied to this domain. As a result, it demonstrated the technical feasibility of a prototype of a portable speech generating device which may be applicable to children with ASD or other DD by utilizing the semantic knowledge based on an ontology.

I. INTRODUCTION

Autism spectrum disorder (ASD), also known as autism, is a group of developmental disabilities (DD) such as lack of social skills, behavior abnormality, and both verbal and non-verbal communication [1]. With the growth of number of ASD population over time, assistive technologies that help reduce the major symptoms of ASD have been actively developed in recent years [2]. This research study focused on language education for children with ASD. Because their brain ability is impaired and/or their social interaction with humans is limited, children with ASD or other DD often face challenges with learning language compared to typically developing (TD) children. Even though the recent technologies contributed to enhance the quality of education service in this domain, there are still remaining gaps. This research project was motivated to discover possible solutions to address those problems.

A. Motivation

The number of children diagnosed as ASD has been increased and became one of the significant health care issues worldwide. The latest statistical data from the Centers for Disease Control and Prevention (CDC) reports that about one in 68 children (or 14.7 per 1,000 children) who are 8-year-old were identified with ASD in 2010 [3]. Followed by this, there is a growing interest and need for how to help and teach people with ASD to overcome their severe symptoms.

In particular, the assistive technology for children with ASD at an early age is important because even though ASD cannot be cured completely, early interventions can greatly improve their learning ability [4-6]. Delay of verbal communication, which is one of the common symptoms in ASD, can also be

improved when treated properly at an early age [7]. However, it has been reported that many children with ASD cannot access special education services, especially in South-East Asia and Africa [8] as well as in the United States [9]. As language skills take an important role for the children to participate better in the community, assistive technology that is easily accessible to young children needs to be explored.

B. Statement of the Problem and Objectives

There are various tools used for language teaching for children with ASD or other DD such as cards, books, and small computer devices. These tools are often helpful as the children need a lot of repetitive procedures to learn new words and sentence structures.

However, even though the children with ASD can learn using these tools in the training environment successfully, they may have hard time generalizing what they learned to real situations. For example, after they learn the word “chair” from a picture of a chair, connecting the word to the picture to the real object also requires a lot of repetitive procedures and proper training methods. Thus, the children also need frequent opportunities to repeat exercises and generalize them in daily life [7] [10]. A system that can be deployed in a home environment and teach them language with real objects around them repetitively would be helpful for such task.

The other problem with teaching children with ASD is that their wide spectrum of symptoms and capabilities differ greatly from person to person. From an educational point of view, this means that each child has very different learning curves that cannot be easily categorized into one area. A helpful system should be able to provide an adaptive and personalized teaching approach based on an analysis of collected data of the child and be able to give feedback to the caregivers.

Moreover, parents of children with ASD face challenges due to the complexity of the disorder itself, which needs intensive diagnosis and care, and difficult access to resources and services for ASD. Lavelle et al. [11] reported that the aggregate direct and indirect cost of caring for a child (e.g. school, therapy, time, etc.) with ASD is at least \$17,081 higher than for a non-ASD child per year. Thus, technology that can be used nearby at low cost is in need.

In order to effectively deal with the problems of language education for children with ASD and to reduce their parents’ economic and other incidental burdens, this research study proposes a cyber-physical system (CPS) that provides language education at home for children with ASD or other DD. Long term goals of this project are to: 1) record, track, and evaluate the child’s achievements from multiple embedded

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devices attached to multiple objects at home, 2) provide an adaptive language learning strategy for the child based on the collected data, and 3) also give feedback to the caregivers. The ultimate goal of this research project is to provide a “language based environment” for children with ASD with real objects present in their casual life based on a CPS home. The term “language based environment” is from [7], which emphasized massive number of daily training trials for children with ASD during the early language development.

C. Scope

As part of the goal, this paper introduces the technical methodology of a prototype system. The target users of the system are young children with ASD or other DD who started learning language, but have low ability in language learning. The stakeholders are families with children with DD who need support and guidelines for special language education at home, but have little knowledge of how to teach.

The system consists of two parts: a button type embedded device and software program for adaptive description generation. A device which can be a part of a CPS is described. The button type device can be placed on an object in a home environment (e.g. a table) and produce speech output (descriptions of the table, e.g. red table, wooden table, etc.) when pressed. It aims to automatically adapt the level of descriptions based on the system’s analysis, but at this stage, we assume the caregiver observes the child and makes decisions which level to play, by using the additional button provided with the device. The software can generate the descriptions of an object, which a user selects, gradually and automatically based on language teaching methodology for children with ASD. It utilized the semantic technology for scalability of the system and in order to provide language education considering semantic features.

II. BACKGROUND

A. Assistive Technologies for Special Language Education

Assistive technologies for children with DD focusing on language education can be categorized into three domains as 1) Augmentative and Alternative Communication Technology (AAC) devices, 2) software applications, and 3) robots. Among these, the first two methods are used at home mostly.

AAC devices include various kinds of assistive and alternative tools for communication, such as with augmented voice or symbols, for those who are low functioning in verbal communication [12]. In the special education field, they are used as a tool to teach simple vocabulary and sentence structures [13]. The simple types of AAC devices are as Fig. 1. These provide recorded speeches when pressed. Young children can use these easily as it only requires minimum technology skills of pressing a button. Also, most of these mid-tech AAC are appealing and motivating to young children with ASD [14]. They are customizable to some extent, but have limits on the number and length of expressions due to the limited sizes and number of buttons. Also, as these devices are static and have no intelligence, it should be edited entirely by a user. Teachers



Fig. 1. AAC Devices (left: GoTalk Button; middle & right: GoTalk+4 and GoTalk+32 [15])

and therapists at a special education center manually record voices or program the device for each child’s lesson. However, parents at home may feel difficult to customize the device by themselves due to lack of knowledge.

Software applications for desktop or tablet computers can provide more varied outputs (e.g. dynamic image display, sounds) and educational strategies (e.g. AAC, game, quiz, storytelling, etc.). These high-tech AAC are appropriate for children who have ability to deal with these complex contents. Also, some children with DD may feel difficult to recognize boundaries of keys on a flat touch screen. The research studies with computer-based training have mostly demonstrated positive results. This is assumed that computers can provide gradual increase of learning tasks, but in an always same format and platform, which corresponds to the propensity of children with ASD to stay in a routine environment [16,17]. However, from an educational viewpoint, there is a gap that children with ASD also need repetitive training for generalization of their learning from these virtual platforms to real situations. Thus, a system that can be attached to daily items around them and give repetitive, but adaptive to their learning achievements would be helpful.

B. Ontological Semantic Technology

The software architecture of this study was built upon a semantic technology, Ontological Semantic Technology (OST) [18-20]. Semantic technology enables scalability and flexibility in terms of system management than traditional IT system. Also, in this domain, the ontology-based semantic knowledge was utilized to generate descriptions of objects automatically considering both semantic and syntactic complexity.

The architecture of OST is based on repositories of world and linguistic knowledge, consisting of 1) ontology, 2) one lexicon per supported language (e.g. English, Korean, Russian, etc.), 3) Proper Name Dictionary (PND), and 4) a common sense rule resource. For this prototype, only ontology and English lexicon were used.

The ontology is a language independent knowledge resource, which consists of concepts and their properties that are connected semantically. In other words, the ontology is a graphical representation of concepts and their relationships in the world, or specific domains of the world. The lexicons are the set of dictionaries of each language, which contain syntactic, morphologic, and semantic information about every word. The meaning of each word’s sense is anchored in the corresponding concept in the ontology. For example, an

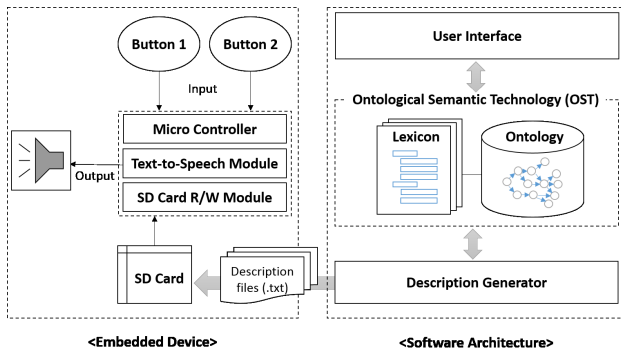


Fig. 2. System Overview

ontological concept/property of red color is linked with a lexeme “red” in the English lexicon and “빨강 (/p'al.gaj/)" in the Korean lexicon.

III. METHODOLOGY

As mentioned in the earlier section, the system consists of two parts: an embedded device and a semantic-knowledge based software program installed in a personal computer used to configure the device. The overview of the system is depicted in Fig. 2.

A. User Interface Program

User interface allows caregivers to select an object that they want to teach and its desired characteristics (e.g. material, color, etc.) of it, so that the program can generate appropriate descriptions about the object that the user has. Once the user enters the information, the program generates the descriptions in progressive order that are proper for the children with DD. The objectives of the application design is as follows:

- Language-interchangeable platform: based on the ontology, a language-independent repository, the application can provide multi-language interface by just changing the supported lexicons.
- Intuitive visual design: it pursues intuitive visualization for any users regardless of education level or familiarity with technology. As a part of this approach, the interface was designed to provide visual cues with not only text, but also images and icons (e.g. showing the color images as well as the list of words for colors).
- Flexibility for users: because the symptoms of ASD appear as a wide spectrum of severity and various characteristics by individual, the tool should provide flexibility which a user can customize it for their own child's case.

Fig. 3 shows the architecture of the application. First, a user chooses an object's name that he or she wants to teach with the device (initial page view). Based on the selected object, the controller retrieves the related properties of the object from the OST ontology. These retrieved possible options (e.g. color, material, size, etc.) are displayed dynamically, both with the words (from the lexicon) and images (from the image pool). Based on the user's input, description generator produces

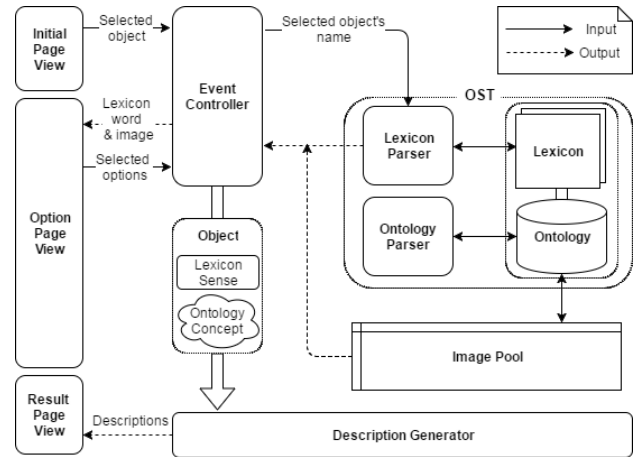


Fig. 3. Architecture of Software Application

the list of descriptions. The user can modify/add/delete the descriptions that is thought to be more suitable for one's child and save them to the device (SD card) in the result page view.

B. Description Generator

Description generator produces multiple levels of descriptions considering both semantic (meaning) and syntactic (grammatical) aspects. The ontology in OST was utilized for semantics, and the syntactic part was derived from the English lexicon. The design of description generation algorithm refers to the literature source of an educational methodology for ASD children, Teaching Language to Children with Autism or Other Developmental Disabilities [7].

The following list summarized the guidelines when teaching initial tact skills (labeling and describing objects) and following receptive skills (listening or reading) from the literature [7]:

- 1) The words should be for items that the child can see frequently in daily life and that the child feels familiar and positive with. Real objects nearby one's surroundings may work better, as they are three dimensional and the child can have time to examine them closely.
- 2) The words should be developmentally appropriate (e.g. do not teach “yes/no”, “more”, “same/different”, or “please”, until the child have enough other words in their vocabulary).
- 3) The first words to be learned should be stable items, not transitory, relative, or abstract.
- 4) The words should correspond to items that are easy to discriminate from one another (e.g. teaching truck and car at the same time may confuse the child).
- 5) The words with relatively easy and short speech sounds (e.g., “aa”, “ba”, “mm”, and “da”; “la” and “rrr” may be much harder).

Taking the above factors into consideration, this study chose physical objects that present in the children's daily life such as furniture, tableware, and parts of building (e.g. window and door). Then, their static attributes (properties)

TABLE I
LEVEL OF SEMANTIC COMPLEXITY

Level	Property	Property name in the OST ontology
1	Color	<color>
	Material	<made-of>
	Parts	<has-object-as-part>
2	Weight	<weight>
	Size	<size>
3	Category	<is-a>

TABLE II
LEVEL OF SYNTACTIC COMPLEXITY

Level	Syntax Structure	Example
1	Noun (N)	Chair
2	Adjective (Adj) + N	Red chair
3	N + copula + Adj	The chair is red
4	N + copula + N	The chair is furniture

that are appropriate to be explained to the children were selected and entered in the ontology. The relationships between these ontological concepts used in our domain of special education were abstracted or simplified compared to the real-world domain ontology. For example, a couch that has leather coverings was represented as “the couch is made of leather” ((couch)-<made-of>-(leather)), instead of “the couch has padding and the coverings of it is made of leather” ((couch)-<has-object-as-part>-(padding)-<has-object-as-part>-(covering)-<made-of>-(leather)). This was done as it is more effective to describe the object with most explicit parts first, instead of describing every details or every steps of it.

Then, English lexemes that match the ontological concepts were entered in the lexicon. In this initial prototype, the part of speech (POS) and semantic information from the lexicon were utilized. The other portions of the lexical information in the lexicon, morphologic and phonetic information, can be used for the list number 5 and to produce more detailed structure of phrases or sentences, but is not used for this prototype.

Table I lists properties in the ontology considered in this study, ordered by the semantic complexity. The first level consists of the properties with explicit and consistent characteristics (color, material, and parts of the object). The second level of properties are relative factors, including weight and size. The last level is the category of an object, which requires cognitive skills of abstracting the features and classifying objects into a group. Table II is the list of syntactic structure in this study ordered by the complexity, low to high. The use of verbs are limited to copula (i.e. linking verbs, e.g. is, are, etc.) as the properties selected in this scope (Table I) does not involve actions, but just static factors that may be observed by children with DD more easily.

The descriptions can be ordered by either meaning-based or grammar-based. It is up to the caregiver’s choice of which one is more thought to be appropriate for the child. The meaning-based ordering provides the descriptions in order of syntactic complexity (Table I) for each semantic complexity (Table II). On the other hand, the grammar-based ordering produces the

Algorithm 1 Meaning-based ordering (semantic complexity prioritized)

Require: C_{target} , ontological concept of the target object; $S \langle P, C_{filler} \rangle$, map of the selected filler concept (C_{filler}) per property (P) regarding C_{target}
for each semantic complexity level (Table I) **do**
 for each P in S **do**
 retrieve noun and/or adjective sense of C_{filler} from the lexicon
 end for
 for each syntactic complexity level (Table II) **do**
 assign the retrieved noun and/or adjective words to the syntactic template and add it to D while avoiding duplication
 end for
end for
return D , list of descriptions

Algorithm 2 Grammar-based ordering (syntax complexity prioritized)

Require: C_{target} , $S \langle P, C_{filler} \rangle$ as defined in Algorithm 1
for each syntactic complexity level (Table I) **do**
 for each semantic complexity level (Table II) **do**
 for each P in S **do**
 retrieve noun or adjective sense of C_{filler} from the lexicon and assign it to the syntactic template; add it to D while avoiding duplication
 end for
 end for
end for
return D , as defined in Algorithm 1

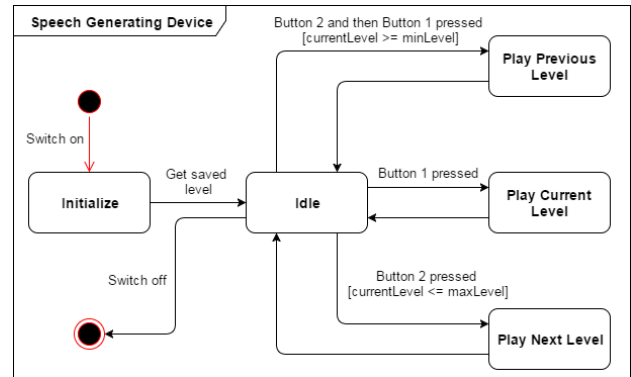


Fig. 4. State Diagram of Speech Generating Device

descriptions in order of semantic complexity for each syntactic complexity. The generic algorithm of each ordering method is depicted as pseudo codes in Algorithm 1 and Algorithm 2.

C. Speech Generating Device

The embedded device designed in this study is a portable speech generating device similar to a single button-type AAC, which can be put on a real object or nearby of it. The hardware

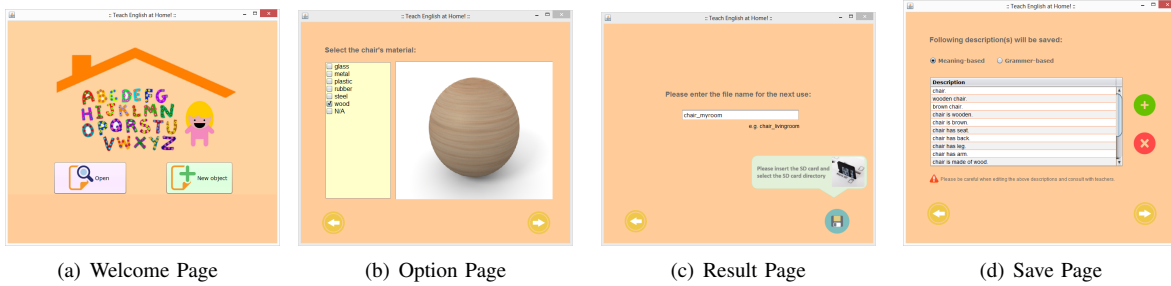


Fig. 5. Software program

is composed of a micro controller, a speaker, two push buttons, a SD card reader/writer module, and a text-to-speech (TTS) module. It plays an audio output of description when the button is pressed. It is processed as below (see Fig. 4):

- Input from buttons: Button 1 is for a child which repeats the current level of descriptions. Button 2 is for the caregiver to traverse the level of the description back and forth. Clicking button 2 increases the level. While the button 2 is pressed and then button 1 is clicked, it decrease the level.
- Output: The SD card has the list of descriptions as separate text files (.txt) once customized from the software program. When the button is pressed, the SD card reading/writing module reads the text file of the selected level and passes to the TTS module. Then, the TTS module produces the audio speech through the speaker.

IV. IMPLEMENTATION AND RESULTS

The software program was implemented in Java.

A. User Interface Program

- 1) Welcome page: There are two menus on the welcome page: 1) start from creating new descriptions with a new object, or 2) retrieve the previously saved object (Fig. 5(a)).
- 2) Initial page: The user selects an object from the list. Filters are implemented to inform caregivers when they select objects that are not advisable by [7]. For example, if the user selected “stool,” but had created “chair” before, the system prompts a warning saying that the child should fully learn and understand the concept of “chair” before teaching a somewhat similar concept of “stool”. This function was done by comparing the ontological concepts linked with the lexemes.
- 3) Option pages: The option pages are created dynamically based on the selected object’s related properties and concept fillers retrieved from the ontology. As shown in the Fig. 5(b), the left side displays the list of words and the right side shows the corresponding image. The item selection is restricted to one per property, except for the <has-object-as-part> property. There is a “not applicable” option in case not appropriate.
- 4) Result page: After all properties are selected, the description generator produces the list of descriptions and

TABLE III
LIST OF DESCRIPTIONS

No.	Meaning-based Description Ordering	Lev.*	Grammar-based Description Ordering	Lev.*
1	Chair	-/1	Chair	-/1
2	Wooden chair	1/2	Wooden chair	1/2
3	Brown chair	1/2	Brown chair	1/2
4	Chair is wooden	1/3	Small chair	2/2
5	Chair is brown	1/3	Light chair	2/3
6	Chair is made of wood	1/4	Chair is wooden	1/3
7	Chair has seat	1/4	Chair is brown	1/3
8	Chair has leg	1/4	Chair is small	2/3
9	Small chair	2/2	Chair is light	2/3
10	Light chair	2/2	Chair is made of wood	1/4
11	Chair is small	2/3	Chair has seat	1/4
12	Chair is light	2/3	Chair has back	1/4
13	Chair is furniture	3/4	Chair is furniture	3/4

*Level (Semantic level (Table I) / Syntactic level (Table II))

displays them on the table (Fig. 5(c)). The user can choose between the two ordering options (meaning-based or grammar-based) and can add/delete/modify the text.

- 5) Save page: After the user confirms the results, the next page (Fig. 5(d)) shows the text field to name the current descriptions for the future use. Then, it is saved with all other data of the current object in the local repository for later use. The generated descriptions are saved to the SD card.

B. Description Generator

Table III is the examples of descriptions with a chair that is specified by a user as brown, wooden, small, and light with a seat, and legs. As shown in the results, the description generator could retrieve data from the OST successfully and provide two different orderings as designed. Regarding the result in the second column of Table III, which is meaning-based ordering, the third column shows that the semantic level increments gradually and the syntactic level also increases in order within the same semantic level. Grammar-based ordering shows the same pattern, but prioritizing the syntactic order. As mentioned in the methodology part, it still has room for improvements in terms of the syntactic structure such as plurals and articles as well as other POS. It can be built upon the current methodology by utilizing more syntactic and morphologic information in the lexicon.

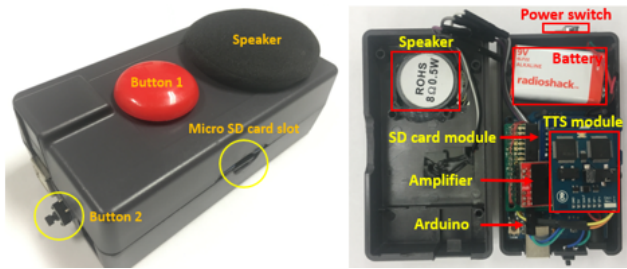


Fig. 6. Prototype of Speech Generating Device

C. Speech Generating Device

Fig. 6 is the picture of the implemented speech generating device as a prototype. The button for a child (Button 1) is placed on the top of the device so that the child can easily touch or press the button. The button for caregivers (Button 2) is hidden on the side of the device. The size and shape of the device can vary. The caregiver of a child can put this portable device nearby or on the targeted object. When powered on, it starts from the level performed lastly before powered off, or starts from the first level if it is new. The caregiver should observe the child and adjust the description level by using the button on the bottom (Button 2). The child can push the button on the top (Button 1) whenever interested and hear and/or repeat the speech from the device. The voice style and color of the button can vary by the child's preference to engage one's interest.

V. SUMMARY AND FUTURE WORK

Children with DD need special language education with real objects much more repetitively than TD children. Thus, this paper proposed the semantic knowledge-based CPS in a home environment for adaptive language teaching for them. As an initial step of the ultimate goal, this study focused on design and development of a single speech generating device with a software application that generates the descriptions automatically based on the modeling of special language education. As a result, this research project demonstrated the technical feasibility of the proposed scope of the system, which can be a foundation for further steps.

Further studies are expected. Firstly, in terms of the description generator and utilizing the OST system, languages other than English will be used. Secondly, the hardware device itself will be improved not only in terms of the interface and appearance, but also adding network ability to build a CPS. At this point, the OST can perform further intellectual functionality such as sharing information between multiple agents and reasoning. The multi-agent platform, such as HARMS model [21,22] will be introduced to manage the CPS operation effectively. Finally, now that this proof-of-concept has been put in place, testing and surveying with the actual users that can benefit from such devices, starting from reaching out to teachers or parents with the children with ASD or other DD will be useful to reflect the practical needs into the system and applying this research study to a real-world scenario.

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