A VISUAL CONCEPT LANGUAGE FOR EMG SPELLER

Mindaugas Vasiljevas, Tomas Šumskas, Ignas Plauska, Robertas Damaševičius

***Abstract**: Assistive technologies provide means for disabled or impaired people to extend their capabilities, communicate and control their environment using alternative and augmentative forms of interaction. Neural-computer interface (NCI) is a communication system that translates neural activity of human muscular system (electromyography (EMG) signals) into commands for a computer or other digital device. The paper discusses the development of the visual concept language for EMG speller (text entry application) based on the application of sound visual communication methodological principles. We present a description of language based on the Speller Visual Communication Language Ontology (SVCLO) developed on the analysis of basic requirements of impaired users living in a closed Ambient Assisted Living environment. Evaluation of the language is given.*

***Keywords**: NCI, neural-computer interfaces, speller, visual concept language, ontology, language modeling*

***ACM Classification Keywords**: H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous*

Introduction

Over a billion people are estimated to be living with some form of disability or impairment [Domingo, 2012]. Today's computer systems are not suitable to be used for such people as the input to computers is still fairly limited to mechanical (keyboard, mouse), audio (speech) and tactile inputs. The design of the hardware and software that enables access of handicapped people to ICT services often fails to take into account the user needs [Dawe, 2006]. Such limitations raise barriers for people with major or minor disabilities such as elderly people with motor impairments in benefiting from the use of modern ICT applications. Therefore, a large number of individuals are at risk of becoming excluded from the information and knowledge society [Gregor & Dickinson, 2006]. To overcome these barriers, new concepts and methods of human-computer interaction (HCI) such as Ambient Assisted Living (AAL) technology devices, systems and interfaces [Memon et al, 2014] must be researched and developed in order to efficiently and effectively address the accessibility problems in human interaction with software applications and services while meeting individual requirements of the users in general.

Communication is an essential part of everyday life. Communicative ability is required for nearly every aspect of life, from meeting our basic survival needs to complex social interactions. Assistive technologies have been proposed to provide for individuals with physical disabilities the alternative channels of communication (or access pathways) through which they can utilize communication systems and thus interact with their surroundings [Cortés et al, 2003]. The access pathway and representation of information used in these systems differ depending on the degree of physical or cognitive disability of the intended user [Guger, 2009].

Neural-computer interface (NCI) is a communication system that translates activity of human nerve system into commands for a computer or other digital device. Most NCI systems work by reading and processing electromyogram (EMG) signals: electro-potentials generated by neuromuscular activation during muscle contraction. Using EMG signals generated by the muscular system individuals with restricted motor abilities can use text-based communication systems, such as the spellers, to spell messages.

Written languages are good for expressing all kinds of communication however they require many typing effort, which for some computer applications or for some specific groups of users may be a tiresome burden. The challenges for entry systems are to develop new interfaces to remove the performance bottle-neck of text entry, which currently are limited in performance, and this in turn limits users’ communication speeds, as well as to bridge the communication gap between users with disabilities, who often rely on text entry methods for their primary communication needs, and society at large [Kristensson et al, 2013].

Augmentative and Alternative Communications (AAC) [Glennen, 1998], aim at complementing or replacing common written or spoken communication systems for those individuals that have such abilities impaired. Examples of AAC are pictogram-based communication systems such as Blissymbols, PCS and Picsyms [Mizuko, 1987], which are based on visual icons or images that represent real objects or abstract concepts to enable individuals sharing internal states, feelings, ideas and experiences. The main advantage of using pictograms rather than text is that recognizing an image is easier than reading text [Norman, 1990]. Therefore, pictograms are often used when verbal messages are not possible or adequate.

A visual concept-based language allows expressing high-level concepts succinctly using a notation tailored to a set of specific domain problems. Such languages are tailored towards a specific application domain, and are based only on the relevant concepts and features of that domain. Therefore, visual languages can be considered as a medium of communication that allows to bridge the gap between the mental model and the problem domain systems and, consequently, to cut the distance between communicating parties in AAL applications.

The contribution of this paper is the design of the visual language for the NCI speller based on the application of sound methodological principles including a model of visual communication, and a formal description of syntax based on using ontologies of domain concepts and signs. Visual language offers a mental vocabulary while used with EMG systems.

Elements and Models of Visual Communication

Any language is a formal system of signs described by a set of grammatical rules to communicate some meaning. In particular, a visual language (VL) is a system of visual signs (i.e., primitive graphical elements, graphemes or pictograms), which represent domain-specific concepts, processes, or physical entities. Spatial arrangement of graphical elements together with a semantic interpretation provides a space of communication for its users. Below we present an analysis of known models of visual communication.

Semantic theory is a specification of the meanings of the words and sentences of some sign system. A sign has three aspects: it is 1) an entity that represents 2) another entity (real thing) to 3) an agent. The aspects are often represented as the Ullman’s triangle of meaning [Ullmann, 1972], which is a model of how linguistic symbols are related to the objects they represent. This triangle explains the separation of language development aspects into syntax (vocabulary of tokens/signs), semantics (grammar rules), and pragmatics (usability). In a visual domain, words are represented by signs and syntax of the language can be described using ontology of signs, and semantics can be described using domain ontology.

A visual language model [Hari Narayanan & Hubscher, 1998] focused on the human use of visual languages and described three objects of interest to investigation of such languages: a computational system, a cognitive system, and the visual display as a communication medium (or channel). Visual representations that encode and convey information appear on the visual display and require visual perception, comprehension and reasoning on the cognitive side, as well as visual parsing, interpretation, and program execution on the computational side. The authors themselves recognize that the model is not full as a more complete taxonomy complemented with a formal system to define semantics is required.

Bertin [Bertin, 2010] analyzed the main elements of visual objects. These could be encoded graphically using 8 visual variables which provide a visual alphabet for constructing visual notations as follows:

shape, size, orientation, pattern, color, hue and two spatial dimensions (vertical and horizontal). Notation designers can create graphical symbols by combining the variables together in different ways.

Physics of Notations is a framework of methodology for developing cognitively-effective visual languages [Moody, 2009]. The framework defines a visual notation that consists of a set of graphical symbols (visual vocabulary), a set of compositional rules (visual grammar), and definitions of the meaning of each symbol (visual semantics). Visual vocabulary includes 1D graphic elements (lines), 2D graphic elements (areas), 3D graphic elements (volumes), textual elements (labels) and spatial relationships. A valid expression (diagram) in a visual notation consists of visual symbols (tokens) arranged according to the rules of the visual grammar. Visual vocabulary and visual grammar together form the visual syntax of the notation. The language meta-model defines mapping of visual symbols to the constructs they represent. The approach has been defined as a scientific theory that allows both understanding how and why visual notations communicate.

Summarizing, the main motivation for developing and using visual languages are: 1) higher level of abstraction, which is closer to the user's mental model and involves manipulation of visual elements rather than letters or words, 2) higher expressive power characterized by two (or more) dimensional relations between visual elements, and 3) higher attractiveness to users motivated by simpler description of complex things. Other advantages of VLs include economy of concepts required for communication, i.e. smaller effort and time required to communicate the same meaning than using textual (alphabet-based language), and immediate visual feed-back.

Modeling the Syntax of Visual Language

A VL is an artificial system of communication that uses visual elements. Any visual language can be characterized by three main elements: lexical definition (symbol vocabulary), syntactical definition (grammar), and semantic definition. VLs differ from textual languages by the type of used symbols and the type of their relation to each other. The designer faces two main challenges when developing a visual language: 1) selection (construction) and design of a visual vocabulary for the developed language based on the needs and requirements of target user group, and 2) selection of the meta-modeling methodology for describing the syntax of the language.

First, a set of symbols is extended from a set of characters (e.g., ASCII, Unicode) to a set of any images. Formally, a visual symbol S_v is defined as a quadruple $S_v = (I, C, M, A)$, where I is the image that is shown to the user of the language; C is the position of the symbol in the visual sentence that defines its context, i.e., the relation of the visual symbols to other symbols; M is the semantic meaning of the visual symbol; and A is the set of actions that are performed when the symbol is activated.

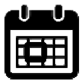
We use ontological engineering methods for modelling and specifying a vocabulary of the language. The symbol vocabulary formally can be defined as ontology of symbols (signs) $O=(D,R)$, where D is some domain, and $R \subseteq D^n$ is a set of relations defined in D. Visual language L_v can be defined as $L_v \subseteq S_v^*, S_v \in O$. In the classic definition of generative string grammars, a grammar G(L) of language L is defined as $G(L)=(N,T,P,S)$, where N is a finite set of nonterminal symbols (grammar variables), none of which appear in strings formed from G, T is a finite set of terminal symbols (grammar constants), $T \cap N = \varnothing$; P is a finite set of production rules that map from one string of symbols to another in the form of $(N \cup T)^* N (N \cup T)^* \rightarrow (N \cup T)^*$, and S is the start symbol, $S \in N$. In a visual language, the ordering of visual symbols is non-linear, therefore, the visual production rules include visual relations R as follows: $((N \cup T)R)^* N(R(N \cup T))^* \rightarrow (N \cup T)^*$.

Further, we analyze and present results of modelling a visual concept language for the BCI/NCI domain. Speller is a typical example of PCS, which establishes a communication channel for people unable to use traditional keyboard and still remains a benchmark for BCI and NCI methods. The requirements for interfaces for impaired users can be formulated as follows [Marinc et al, 2011]: 1) Limited access to details: complex and vital details of the system have to be hidden to avoid user overwhelming and trapping. 2) Self-learning: detected common patterns in the behavior of the user should be used to automatically create rules or shortcuts that speed and ease up the use of the system. 3) System interruption: Impaired users have in most cases no idea how the system is working, therefore easy cancellation of system’s activities must be ensured.

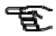
When designing a vocabulary the main concerns are as follows: 1) Understandability. The designers want to communicate ideas using visual language with as less noise as possible. This requires that the mental models of designers must be “shareable”, i.e., the symbols used to communicate meaning must be easily recognizable and interpretable. The meaning of symbols must be known intuitively. 2) Usability. The symbols must be designed using a principled methodology, and their usability must be thoroughly evaluated using quantitative metrics [Plauska & Damaševičius, 2013] and/or qualitative surveys.

For our design task we have decided to select a subset of symbols from The Noun Project (http://thenounproject.com/), while the remaining few ones are custom-built. The advantages of such choice are as follows: 1) the signs are simple, easily recognizable, legible and understandable; 2) the signs contain a minimum amount of information (or “conceptual baggage” [Anderson et al, 1994]) required to communicate a message. In Table 1, we present some of the visual graphemes of the proposed visual concept language.

Table 1. Example of Graphemes (visual tokens) of language and their interpretation

Visual sign	**Interpretation**
Superconcepts	
	Emotions
	Location/position
	Actions
	Communication
	Time
	Body. Body parts
	Medical
Concepts	
	Happy
	Sad
	Pain
	Cold
	Warm. Heat
	House. Living environment
	Hospital
	Call
	Help
	Read
	Today
	Tomorrow. Future
	Yesterday. Past
	Thing
	Ambulance

	Medicament
	Hand. Arm
	Head
	Heart
	Leg. Foot
	Lungs

	Person
	Doctor. Nurse
	Reference sign
	Reference sign
	Negation
	Question

Modeling the Semantics of Visual Language

A common tool for expressing and formalizing knowledge about major domain concepts and their relationships is ontology. Ontology is a formal data model expressed in a computer readable notation that seeks to provide a definitive and exhaustive classification of entities in a domain [Smith, 2004]. Ontology aims to define an unambiguous vocabulary of terms shared across domain experts and taxonomy of concepts to model a domain of interest. In particular, it covers individuals (instances of concepts), classes and sets (groups or types of concepts), attributes (data attached to individual concepts), and relations (how concepts are related to each other).

Ontology can be seen as the metamodel specification for an ideal language to represent phenomena in a given domain in reality, i.e., a language which only admits specifications representing possible state of affairs in reality [Guizzardi, 2007]. The use of ontologies as shared conceptualizations of knowledge minimize the "noise" (i.e., misunderstanding, etc.) introduced during the communication process and allows logical reasoning and inference over signs as representation of meaning.

To develop ontology, first, the scope and objectives of ontology must be identified. Next, knowledge must be discovered, elicited and extracted from the domain of interest. Third, the ontology must be specified using a standard language (we use OWL). Finally, the ontology must be validated.

The Speller Visual Communication Language Ontology (SVCLO) presented in this paper is based on the analysis of basic requirements of impaired users living in a closed AAL environment. It includes description of concepts, which are a necessity for daily communication and includes concepts from the following domains: 1) Temporal; 2) 2) Emotional; 3) Action; 4) Medical care; 5) Body part; 6) Domotic; and 7) Basic needs. Signs ontology serves as a connector to link visual signs with the concepts of SVCLO.

The criteria for designing the SVCLO ontology differs from criteria used to design other ontologies. While other ontology tend to be as specific as possible to cover all concepts of the domain (domain ontologies) or as wide as possible (upper level ontologies), our ontology is design to cover as few concepts as possible while describing only those concepts that are necessary for communication. Our ontology is a subset of the union of the following ontologies describing the domains of interest as follows:

Temporal: Several temporal ontologies exist such as OWL-TIME, however there are too technical (e.g., OWL-TIME describes the temporal content of Web pages and the temporal properties of Web services. but lacks such basic temporal concepts as yesterday, today, tomorrow). Other temporal ontologies are also known: There already exist ontologies of temporal concepts from both commercial (e.g., time ontology in Cyc [Lenat, 1995]) and academic sources (e.g., a reusable time ontology [Fikes & Zhou, 2002]; time ontology in SUMO (Suggested Upper Merged Ontology) [Niles & Pease, 2001]. For Cyc time ontology only the vocabulary is publicly available. SUMO is large upper ontologies encoding common sense knowledge, and hence more focus on abstract and philosophical concepts. Reusable time ontology also lacks basic concepts of time. The temporal part of the proposed SVCLO ontology is based on the core concepts taken from OWL-TIME ontology and extended with basic temporal concepts from WorldNet. It is presented in Figure 1.

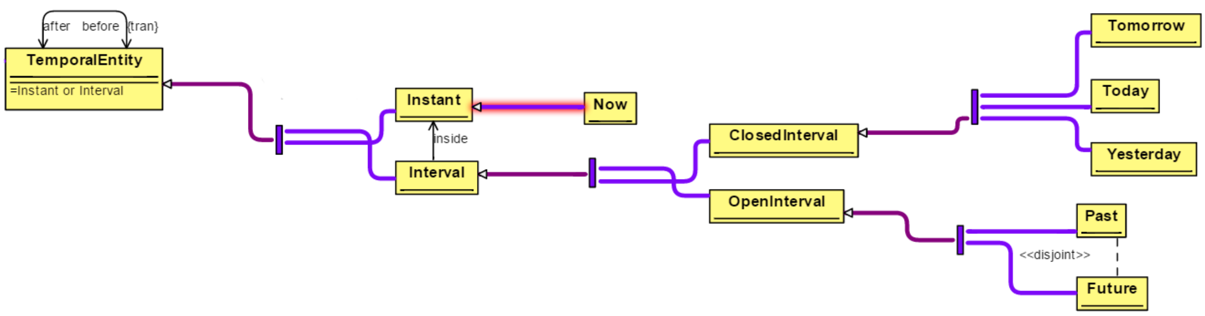


Figure 1. Temporal ontology subset of SVCLO

Emotional: The emotional/affective state of impaired people is an important part of their world. There are many classifications of emotions known in the literature (e.g., Cube of Emotions [Lövheim, 2011], PAD emotional state model [Mehrabian, 1980], Wheel of Emotions [Plutchik, 2001], etc. There are some significant studies on emotion tools and ontology. The Emotion Markup Language (Emotion ML) is being developed by The W3C (World Wide Web Consortium). Human Emotion Ontology (HEO) [Grassi, 2009] supplies a wide set of properties to describe emotions by category. OntoEmotion [Francisco, 2012] describes the emotion domain by categorizing the emotion-denoting words. Our proposed ontology introduces the basic class Emotion and a set of related classes and properties expressing the high level descriptors of the emotions as the 6 archetypal emotions (anger, disgust, fear, joy, sadness, surprise) [Eckman, 2003]. The aim of the ontology is to allow the user to express his/her emotional/sensational state. It is presented in Figure 2.

Action: Several action ontologies exist (see, e.g., [Kemke, 2001]). The aim of our ontology is to describe basic actions and interactions of the impaired user. It is presented in Figure 3.

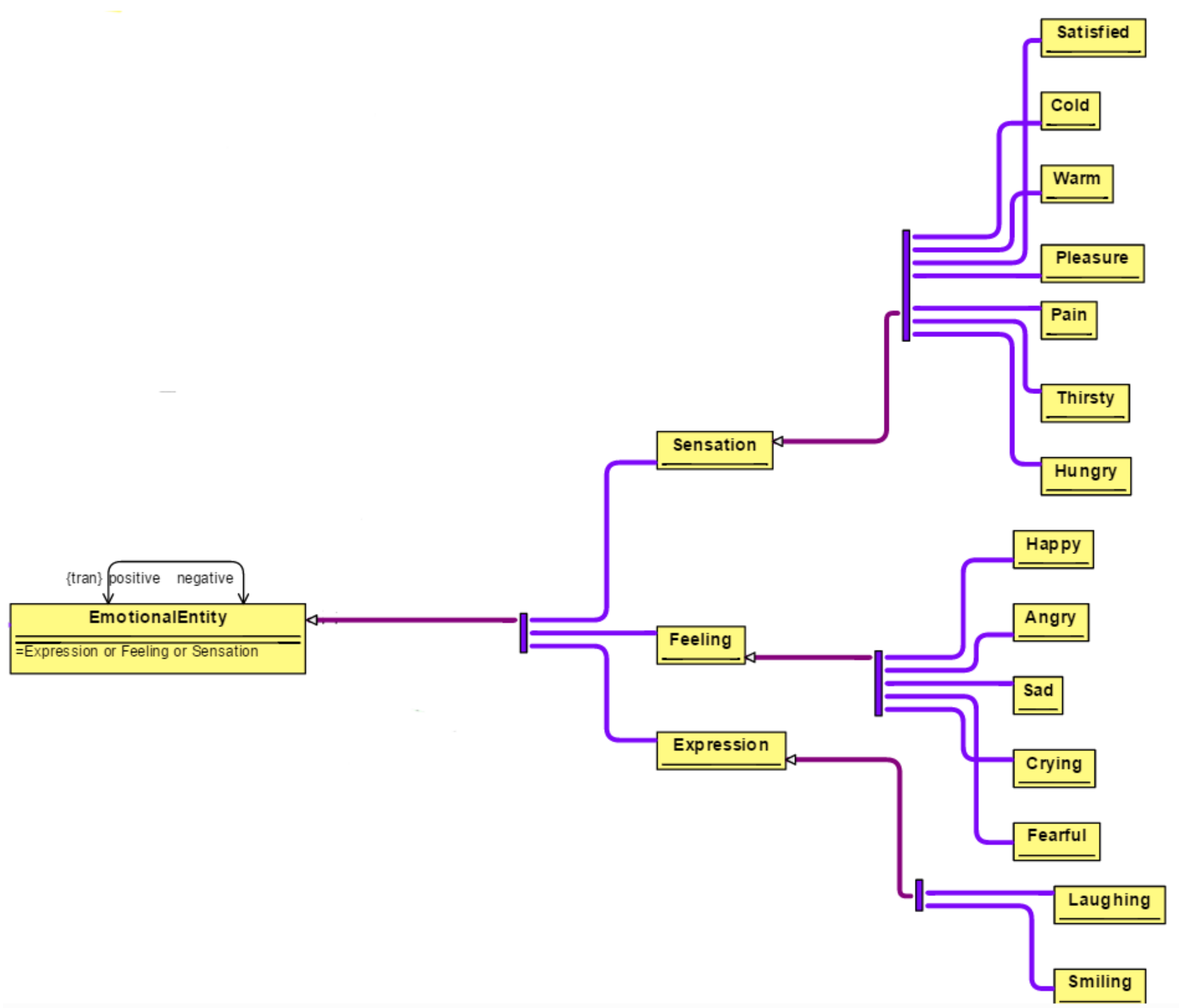


Figure 2. Emotional ontology subset of SVCLO

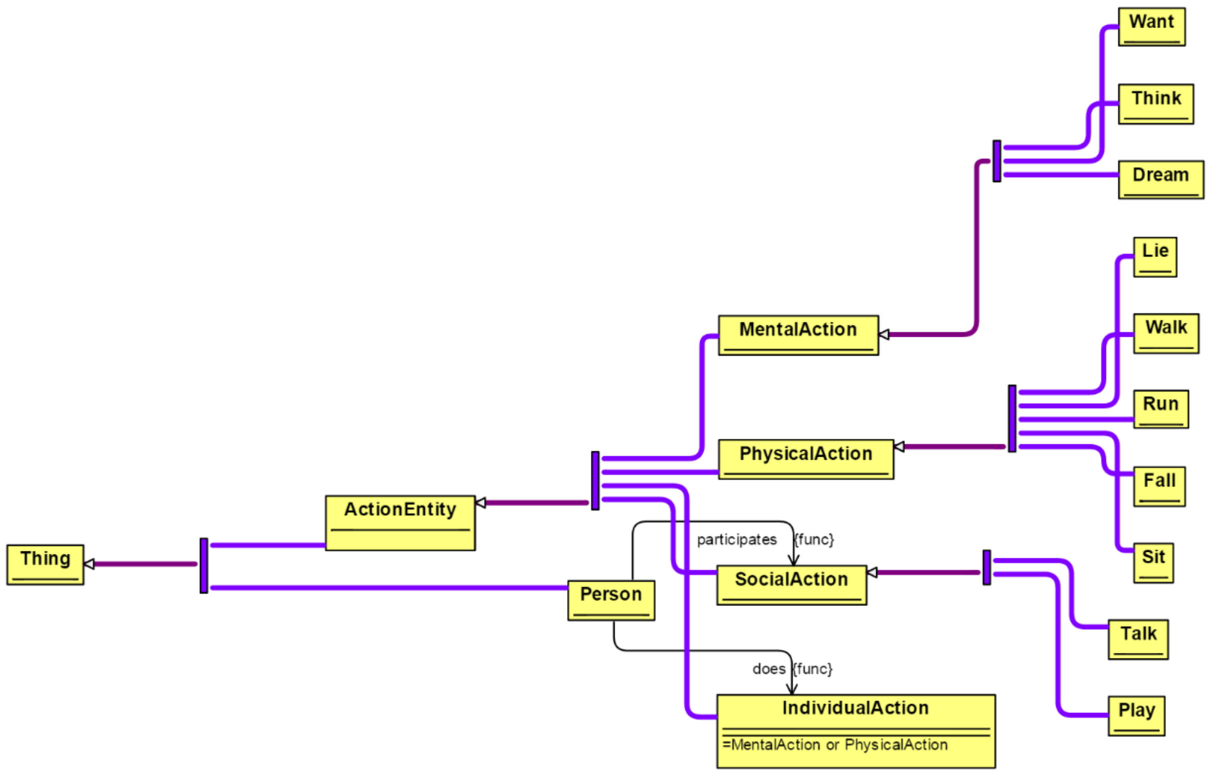


Figure 3. Action ontology subset of SVCLO

Medical care: Several ontologies exist, which cover the domain of healthcare and medical care, such as Domain Ontology for Mass Gatherings — DO4MG [Zeshan & Mohamad, 2012]. The aim of the proposed ontology is to describe basic healthcare-related needs of an impaired person. It is presented in Figure 4.

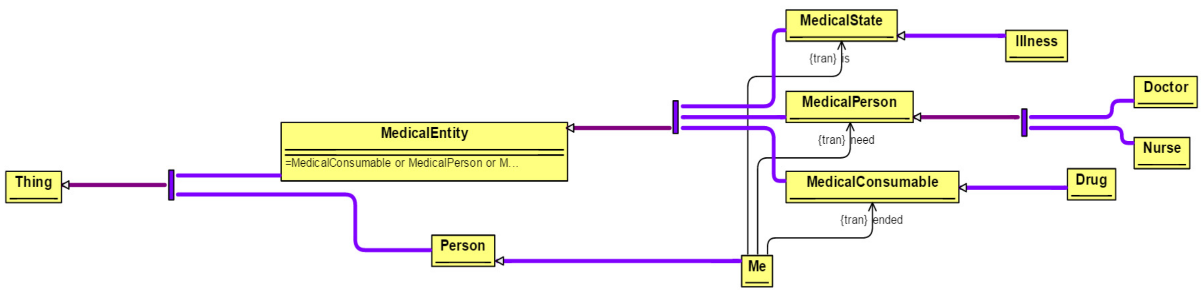


Figure 4. Medical care ontology subset of SVCLO

Body parts: In our ontology, we us a very small subset of the Foundational Model of Anatomy Ontology (FMA), a reference ontology for the domain of anatomy [Noy et al, 2004]. FMA is spatial-structural ontology of anatomical entities and relations which form the physical organization of an organism. It contains approximately 75,000 classes and over 120,000 terms. Our ontology has a small number of body part concepts representing knowledge of average person on his/her body parts. It is presented in Figure 5.

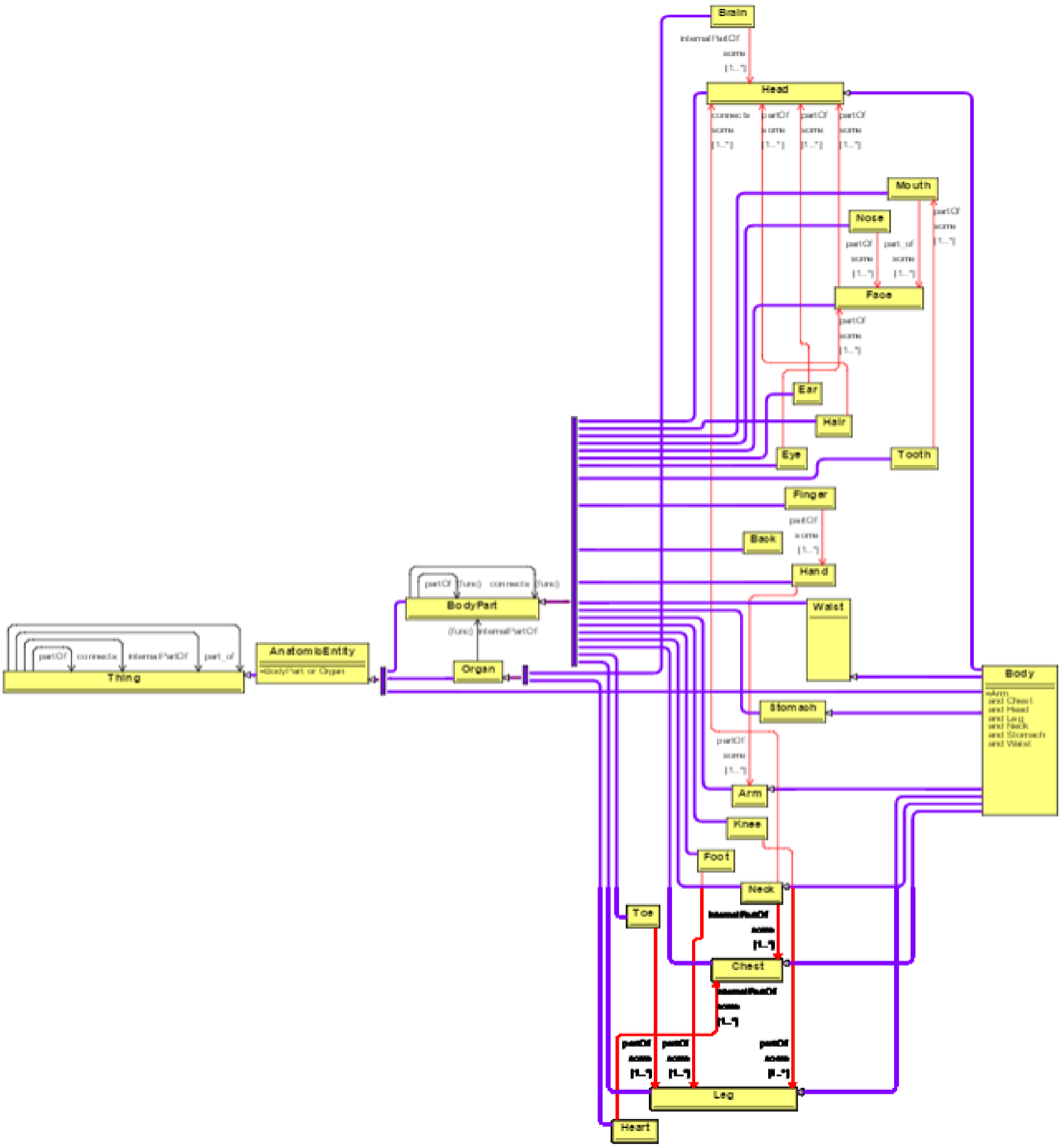


Figure 5. Body parts ontology subset of SVCLO

Domotic objects: Domotic object ontology describes spatial locations and items constrained to the closed space of AAL. Several similar ontologies exist such as an ontology of concrete spatial objects for indoor environments, based on DOLCE-Lite, for the application of ambient environments and assisted living, designed by Universitat Bremen [Bateman & Farrar, 2004], as well as The DnS (Descriptions and Situation) ontology, with an extended vocabulary for social reification [Gangemi, 2007], as well as DogOnt – an ontology for intelligent domotic environments [Bonino & Corno, 2008] and an ontology for smart spaces [Abdulrazak et al, 2010], and FurOnt – the Furniture Ontology [Miori & Russo, 2012]. Our ontology consists of two parts: The Domotic sub ontology includes an integrated taxonomy of domotic concepts. The Furniture Ontology is made up of a simple taxonomy of home furniture. It is presented in Figure 6.

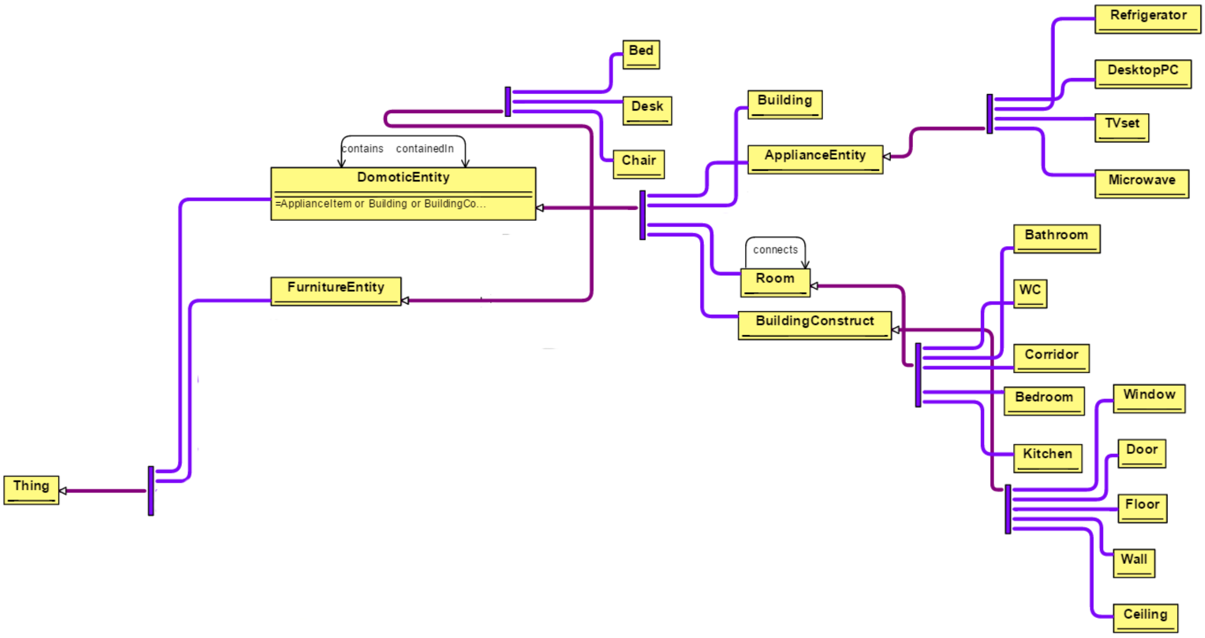


Figure 6. Domotic object ontology subset of SVCLO

Basic needs: similar ontologies exist such as Humanitarian Assistance Ontology (HAO) [Jihan & Segev, 2014] and several others (see a survey in [Liu et al, 2013], which describes basic humanitarian needs of people in crisis situations, e.g., water/drink, food/eat and sanitation/hygiene). The basic needs ontology is presented in Figure 7.

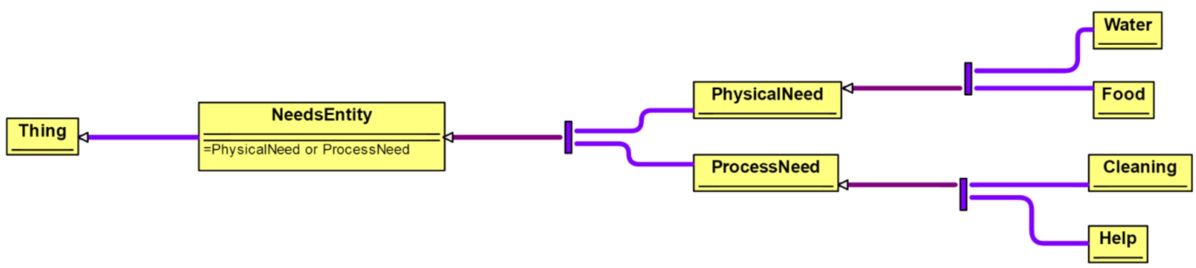


Figure 7. Basic needs ontology subset of SVCLO

Sign ontology. Sign ontology describes the taxonomy of signs, their visual appearance and relates their meaning to the concepts from other ontologies. Know examples include Road Sign Ontology (http://www.iiia.csic.es/~marco/ontologies/2011/7/roadsign-core.owl) and Smiley Ontology [Radulovic et al, 2009]. A fragment of ontology is shown in Figure 8 (only few concept signs are presented due to space limitations).

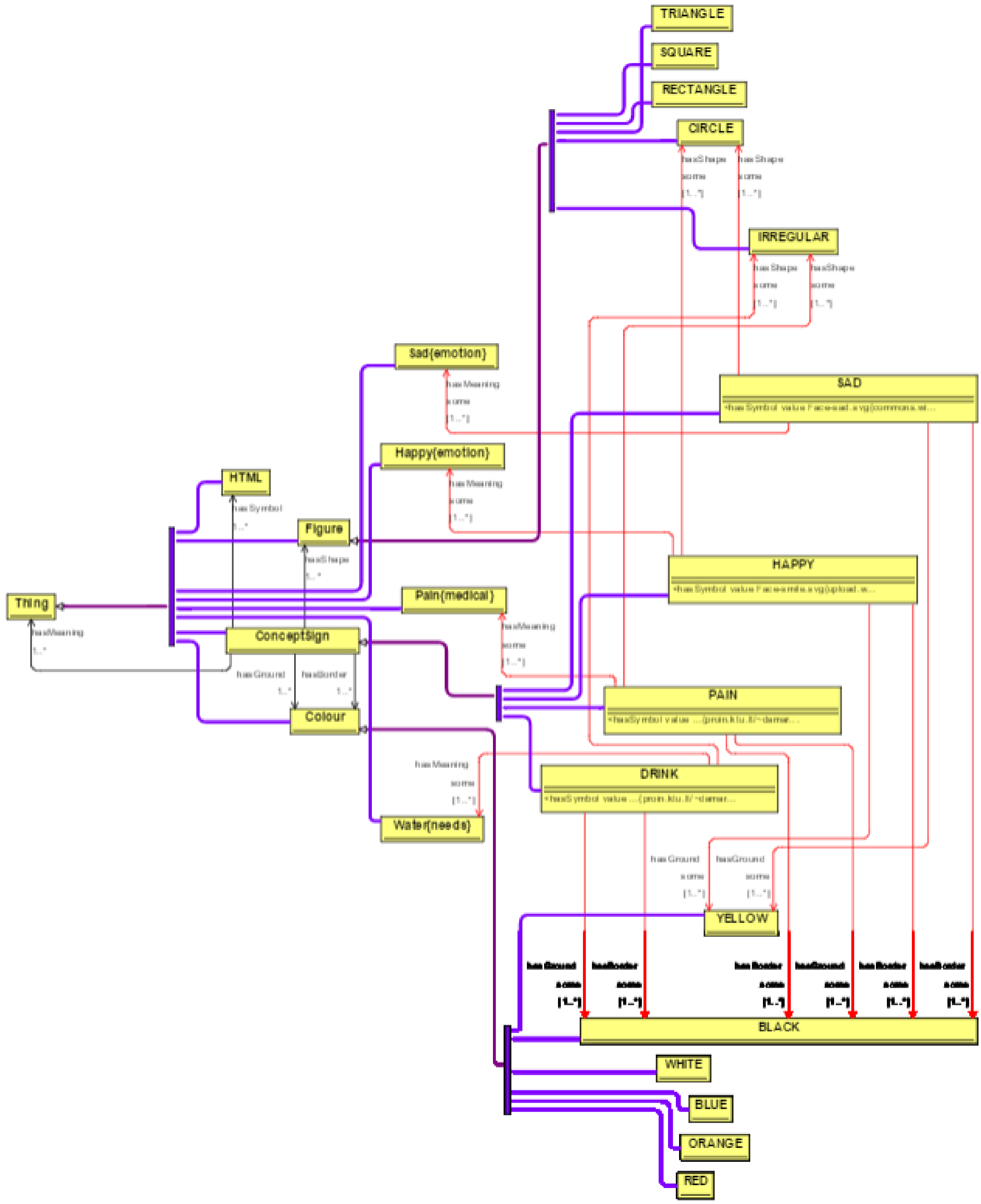


Figure 8. Sign ontology subset of SVCLO

SVCLO ontology has been evaluated using the OWL metrics tool. The results are presented in Table 2.

Table 2. Characteristics of the proposed ontology

Metric	Value
Class count	135
Object property count	24
Logical axiom count	239
Object property axioms count	18

Experimental Validation of Visual Concept Language Based EMG speller

A screenshot of the developed visual concept-based interface of the EMG speller is given in Figure 9. The visual concept-based interface is organized using a hierarchical structure. It consists of symbol matrixes connected with each other by references. Each reference is represented as an icon of particular domain. Each domain matrix as well as the root matrix can be extended easily by adding new icons (concepts) to the particular domain matrixes. Also each icon (concept) in particular domain could contain a reference to the specific subdomain matrix. The interface of the application has the following parts: 1 – zoom control, 2 – representation of raw EMG signal, 3 – concept matrix, 4 – entered visual concepts, 5 – translation to text panel, 6 – concept history.

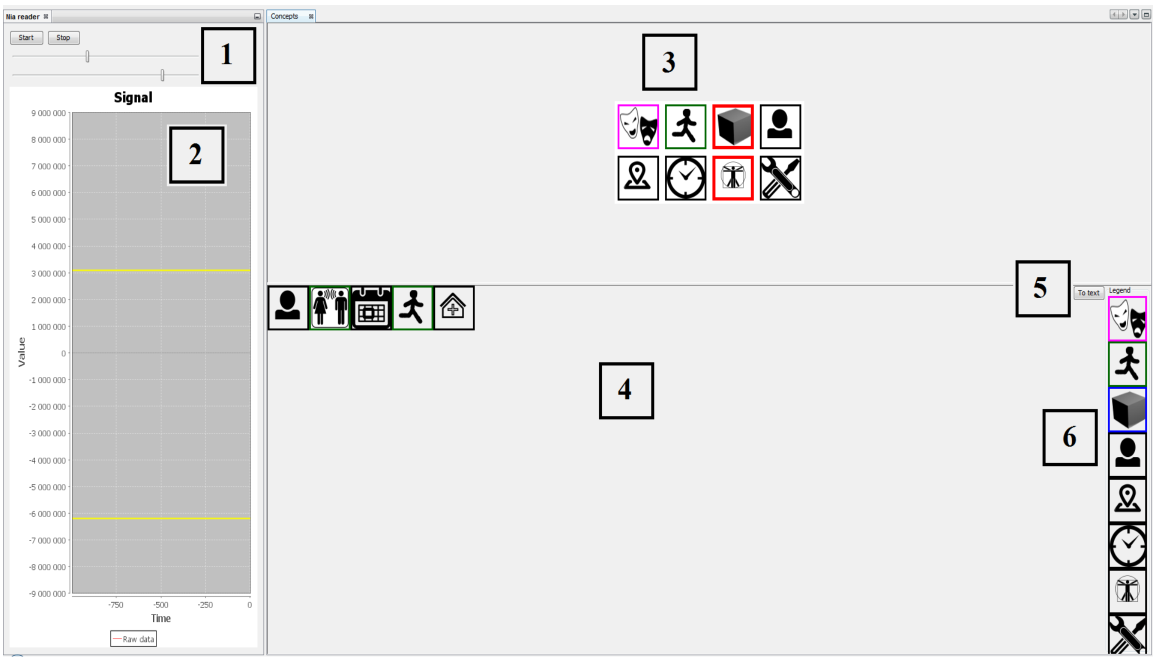


Figure 9. Visual concept-based interface of developed EMG speller

In a typical text entry experiment, the participant is shown a short phrase (the intended text), and is then asked to enter the phrase into the device (the transcribed text) while the speed at which it is done and the accuracy with which the text is inputted is measured. One of the main problems here is the selection of an appropriate benchmark collection (dataset) of text phrases for evaluation of a text entry system. These sets are designed usually to be moderate in length, easy to remember and representative of the target language. As demonstrated by [Lyons & Clawson, 2012], the choice of phrase sets has an impact on potential typing performance. The existing (known) phrase dataset suffer for being too complicated for using for people with disabilities in the AAL systems. For example, the phrase set presented in [MacKenzie & Soukoreff, 2003] contains such impractical phrases as "I can see the rings on Saturn", which is highly unlikely to be used by an impaired person in a domestic environment. The phrases in this dataset phrases in this set targeted mobile device users, but were not written by mobile device users and are most likely not very representative of actual mobile messages. Further, it is unknown whether these phrases are in fact easy for participants to remember. Another dataset presented in [Vertanen & Kristensson, 2011] contain text messages extracted from the publically available Enron email corpus and contains manager communication. The phrases it contains mostly focuses on a narrow topic of meeting arrangement (e.g., "Interesting, are you around for a late lunch?", "Are you going to join us for lunch?", "How about 9 in my office on 3825?") and mostly are not relevant for the AAL domain, too. James [James & Reischel, 2001] used newspaper sentences or sentences that are supposed to emulate a conversation. Kano [Kano, 2006] designed Children's Phrase Set (CPSet) is adapted for use with children. The set contains 500 phrases taken from children's books and nursery rhymes and is designed to be suitable for anyone above the age of 6 years old. Another disadvantage of the commonly used datasets is that they usually contain a high number of so called trigger words (e.g., 'and', 'the', 'to' and 'it'), which may cause interpretation difficulties for people with minor cognitive disabilities such as suffering from dyslexia [Kano, 2005], therefore to ensure the validity of the evaluations, the use of these trigger words should be avoided.

Our set of phrases have been constructed to be as much simple as possible and to contain the concepts that describe the most simple needs and states of an impaired person living in a closed domotic environment. The example of such phrases with corresponding sequence of visual pictograms is presented in Table 3. Note that translation between text and visual concept sequence is not unique: the pictograms could be used in another order with the same meaning conveyed.

Table 3. Example of text phrases and corresponding visual sequences to enter

Textual phrase	Length, symbols	Visual sequence	Length, symbols
I feel pain in the heart	24		4
I need medicine	15		3
Call ambulance to me	20		4
Will you come tomorrow to me?	29		5
It is cold at home	18		2

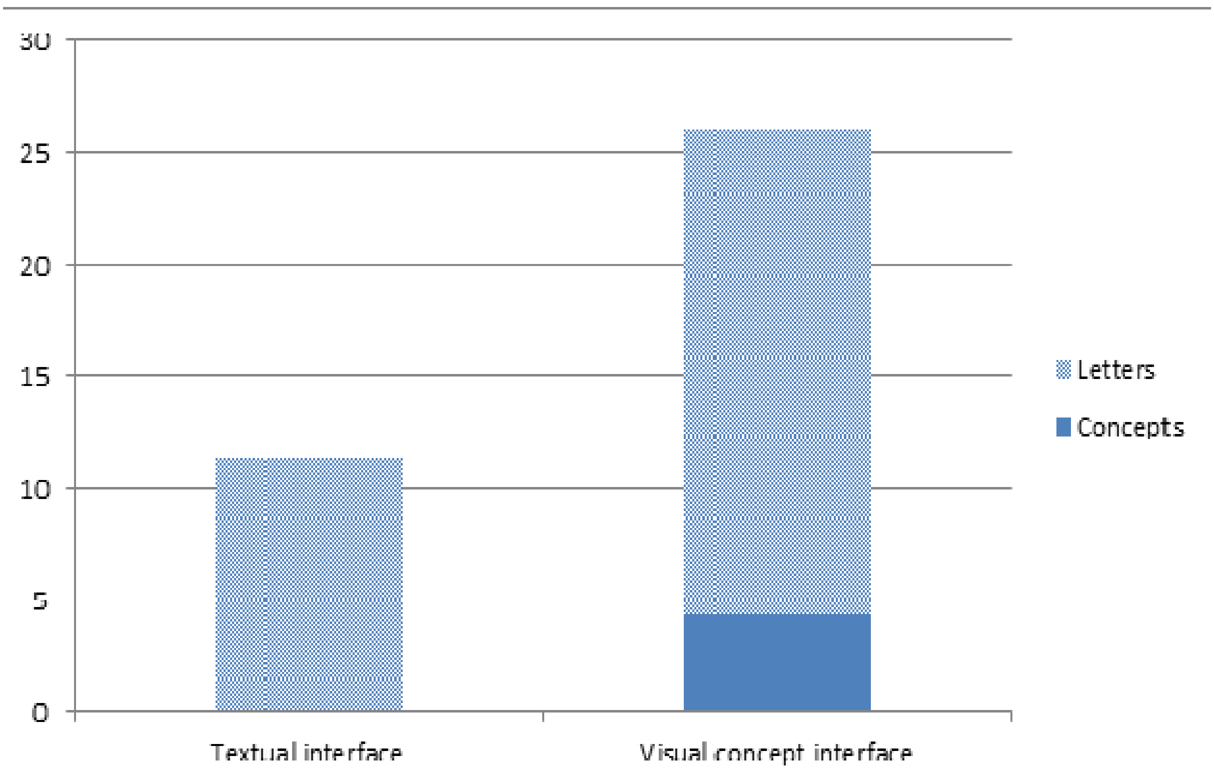


Figure 10. Input speed of visual concept-based speller

Comprehensive experimental evaluation of the visual concept based EMG speller application is given in [Vasiljevas et al, 2014a] and [Vasiljevas et al, 2014b] and is not repeated here. The main results are reproduced in Figure 10. Input speed is measured as the average time required entering a set of texts. Using the speller the users have achieved the input speed of about 4.3 concepts/min, which considering the length of corresponding textual phrases corresponds to 26 letters/min. This result can be explained by the fact that the average length of a word in English is about 5 letters. Considering that using the textual-only input interface we have achieved only 11.35 letter/min input speed, the use of a visual concept based interface allowed us to double the speed of text entry.

Conclusion

The paper describes the ongoing and continuing work in the development of visual concept based EMG speller to be used by impaired people in the assisted living environment. The main results of the paper are as follows. Visual concept-based language has been designed to have a simple, usable and attractive vocabulary in order to be easy to learn and understand by impaired people with limited motor or cognitive abilities. The language addresses the main problem of current NCI/BCI systems (low input speed) by moving the abstraction level of communication from textual to visual one thus reducing the need of text entry actions and reducing the probability of entry errors.

The concepts of the language are chosen to represent only essential needs, feelings, body parts and things of a person living in a closed domotic environment. The vocabulary and semantics of language has been described formally using elements of ontology engineering. The set of visual symbols (graphemes) has been chosen considering the theoretic principles of visual communication, which includes the consistent use of visual variables (shape, color and orientation) and familiarity of visual signs to avoid significant semantic misinterpretations when using the language.

The problem of constructing a set of benchmark phrases for evaluation of NCI/BCI spellers has been identified.

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Authors' Information

Mindaugas Vasiljevas *– PhD student at Software Engineering Department, Faculty of Informatics, Kaunas University of Technology, Studentų 50-409a, Kaunas, Lithuania; e-mail: mindaugas.vasiljevas@ktu.lt*

Major Fields of Scientific Research: Neural-Computer Interface, EMG

Tomas Šumskas *- MSc student at Software Engineering Department, Faculty of Informatics, Kaunas University of Technology, Studentų 50-409a, Kaunas, Lithuania; e-mail: tomas.sumskas@stud.ktu.lt*

Major Fields of Scientific Research: software engineering, Neural Computer Interface

Ignas Plauska *- PhD student at Centre of Real Time Computer Systems, Faculty of Informatics, Kaunas University of Technology, Studentų St. 50–214c, Kaunas, Lithuania; e-mail: ignas.plauska@ktu.lt*

Major Fields of Scientific Research: visual languages, robotics, Internet-of-Things

Robertas Damaševičius *– Prof. at Software Engineering Department, Faculty of Informatics, Kaunas University of Technology, Studentų 50-409a, Kaunas, Lithuania; e-mail: robertas.damasevicius@ktu.lt*

Major Fields of Scientific Research: software engineering, Brain Computer Interface, Neural Computer Interface, data mining