iBeacon and HCI in Special Education: Micro-Location Based Augmentative and Alternative Communication for Children with Intellectual Disabilities

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Abstract
Daily communication is essential for everyone, including people with communication difficulties. While a number of augmentative and alternative communication (AAC) technologies have been developed for users with complex communication needs, their usage still remains a challenge for those with cognitive impairments. This extended abstract presents our work in AAC for non-verbal students with intellectual disabilities. We enhance existing AAC solutions with iBeacon-based ranging and micro-location detection capabilities to reduce user's cognitive load when interacting with the user interface. Our system has been piloted in a special education school for students with moderate intellectual disability. We report our contextual field studies, system design, and implementation experience; and hope to engender further discussions on HCI in special education.

Author Keywords
Beacons technology; HCI in special education; augmentative and alternative communication (AAC); intellectual disabilities; context awareness services.

Augmentative and Alternative Communication (AAC): "*AAC is a set of tools and strategies that an individual uses to solve everyday communicative challenges*." (International Society for Augmentative and Alternative Communication, ISAAC) [9].

Intellectual Disabilities: "*Intellectual disability is a disability characterized by significant limitations in both intellectual functioning and in adaptive behavior, which covers many everyday social and practical skills*." (American Association on Intellectual and Developmental Disabilities, AAIDD) [1].

Beacons Technology: Beacons are Bluetooth Low Energy (BLE) devices that constantly send out radio signals which are identifiable by nearby mobile devices. iBeacon was introduced by Apple in 2013 [2]. Google also releases the Eddystone BLE beacon profile in July 2015.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous; K.4.2. Assistive technologies for persons with disabilities.

Introduction
Well-designed information and communication technologies can enhance the quality of life of every member in a society, including those with special needs. Thoughtful HCI design that takes user cognitive and motor limitations into account is of particular importance to support children with special educational needs (SEN), and can have great potential to empower their learning and development at subsequent stages in life. The HCI community has also begun to pay more attention to users with various disabilities, including children with complex communication needs [8].

People with complex communication needs do not have the necessary abilities (e.g. cognitive abilities and motor skills) to meet their daily communication needs. They include those with developmental disabilities (e.g. intellectual disability), cognitive and linguistic impairments (e.g. aphasia and dementia), and those in acquired medical conditions that result in speech limitations. They often employ augmentative and alternative communication (AAC) [4], which are methods and approaches to supplement or substitute verbal communication such as speech or writing, to conduct daily communication. Picture communication symbols are often used in AAC for non-verbal individuals to express themselves. Figure 1 (on next page) shows a physical picture symbol board on the classroom wall in an SEN school.

Over the recent years a number of AAC technologies, such as portable electronic devices and mobile apps that implement picture and symbol communication boards, have been developed to enable users with complex communication needs to express themselves by ways other than natural speech.

Motivation and Current Challenges
A significant proportion of individuals with developmental disabilities are unable to use verbal means to meet with their daily communication needs. Despite of the increased availability of AAC technologies, their usage still remains a challenge for this special user group. For example, AAC interfaces can impose different levels of motor, cognitive, sensory perceptual, and linguistic learning demands for the users [12], which makes the user interactions particularly challenging for users with intellectual disabilities.

Related Work
Recent advances in mobile and interaction technologies bring about many new opportunities to support users in ways not possible before. Our work is one of the early efforts that realize micro-location based AAC with iBeacon. In terms of the most relevant existing works, a context-aware AAC tool (TalkAbout) based on GPS and Wi-Fi localization has been developed for people with Aphasia [10], and a context-aware AAC has been developed using smart phone default sensors [14]. A few preliminary discussions on iBeacon for assistive technology were also offered in [5].

Our Contribution and Potential Impacts
Our system extended beyond the existing works by achieving accurate indoor tracking and micro-location context-aware AAC on a mobile device with Bluetooth Low Energy (BLE) beacons. Our system has been piloted in a special education school for students with

Figure 1: Picture communication symbols and a picture board inside a classroom of an SEN school.


Figure 2: Observations in contextual field studies: (top left) paper-based AAC tools being used in the school, (bottom left) classroom scenario showing non-verbal students communicating with picture cards, and (right) a personalized communication

moderate intellectual disability. We hope our initial work can echo to the conference theme as well as the recent call from the HCI community. We also hope to solicit input from HCI researchers and practitioners on this ongoing work, and engender further discussions on HCI in special education.

Contextual Field Studies

Understanding Our Users and Their HCI Needs

The primary users of our system are the students from Caritas Resurrection School in Shatin, Hong Kong (we refer to it as "the school" in the rest of the abstract). The school provides primary and secondary school education (equivalent to K1 to K12) for students with moderate intellectual disability (IQ ranged between 40 and 50-55). Similar to a significant portion of students with intellectual disability, our users also experience multiple developmental delay and disabilities including autism spectrum disorders and motor disabilities.

People with intellectual disabilities have significant weakness in verbal working memory (while their visual-spatial working memory may be a relative strength) [6]. Learning occurs when new contents are incorporated into long-term memory via the extremely limited working memory [13]. Therefore in designing UI for students with intellectual disabilities, it is very important to minimize unnecessary cognitive loads so as to free up cognitive resources for learning.

Understanding the Existing AAC Practice

The school adopts AAC as the communication method between students and teachers (including the caregivers) (Figure 2). Each of the students has a personalized hardcopy "communication booklet" which contains paper cards of picture communication symbols that have been learned and are related one's daily use. Examples of the types of symbols in use include those for expression of emotion, needs, and wants; as well as those showing different physical objects inside the school environment. Each of the personalized communication booklets is manually maintained by the class teachers, speech therapists, and the student's own parents (e.g. insert newly learned picture cards).

Understanding the School Environment

The school has 5 floors with a total area of about 1,400 square meters (which is a typical SEN school size in Hong Kong). The compact school building with a small campus size imposes a technical challenge to traditional location detection means such as GPS. We selected three locations: covered playground, a classroom, and the canteen as our pilot installation locations. As shown in figure 4 on the next page, paper-based picture communication symbols and photos are displayed on the walls in each of the rooms accessible by the students (such as the canteen, classrooms, and occupational therapy rooms) to provide a medium of communication between students and teachers.

System Design and Implementation

Our system aims to provide context-aware AAC within classroom settings. The key technical enhancement that our system has made over current AAC solutions is its ability to achieve accurate indoor user tracking using the iBeacon micro-location technology. Our system includes the following service components:

1. Basic AAC functions e.g. picture cards selection;
2. Adaptive and personalized user interface (UI) for students with different level of cognitive and motor disabilities and usage patterns (partially implemented in the current version);

Figure 4: School environment at the implementation site: (upper and lower left) SEN functional classrooms and (right) context-related picture communication symbols and pictures inside a classroom.

3. Micro-location detection and user tracking;

4. Learner management, e.g. user login and user learning profile maintenance; and

5. Learning analytics (to be implemented in the full version).

System Overview

The overall system is shown in figure 5. Our system composed of (1) beacons (Estimote Beacons), (2) Android mobile app client (for students), (3) web client (for teachers, speech therapists, and caregivers), (4) backend server, and (5) database for operational and learning data storage.

Implementation

A preliminary version of our system has been developed. It implements most components except the personalized UI and the learning analytics functionality. We developed and tested a proof-of-concept app called "Situation Chat". There are three sets of picture cards which correspond to three different locations namely (1) classroom, (2) canteen, and (3) playground. Our prototype has been installed in tablets (Huawei T1-821w with Android 4.4 OS and Bluetooth 4.0 connectivity) and a set of Estimote beacons (Figure 6). When the user enters one of these three places, the mobile app can automatically determine the current location of the user and display only the picture cards that are associated to the corresponding location.

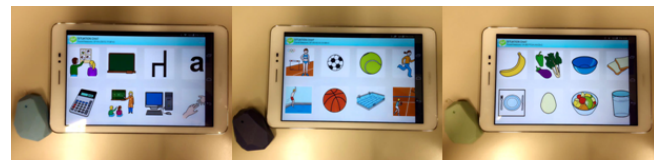

Figure 6: The proof-of-concept mobile app installed in a BLE enabled tablet that can display contextually related picture cards for classroom (left), playground (middle), or canteen (right) according to the UUID of the nearest detected beacon.

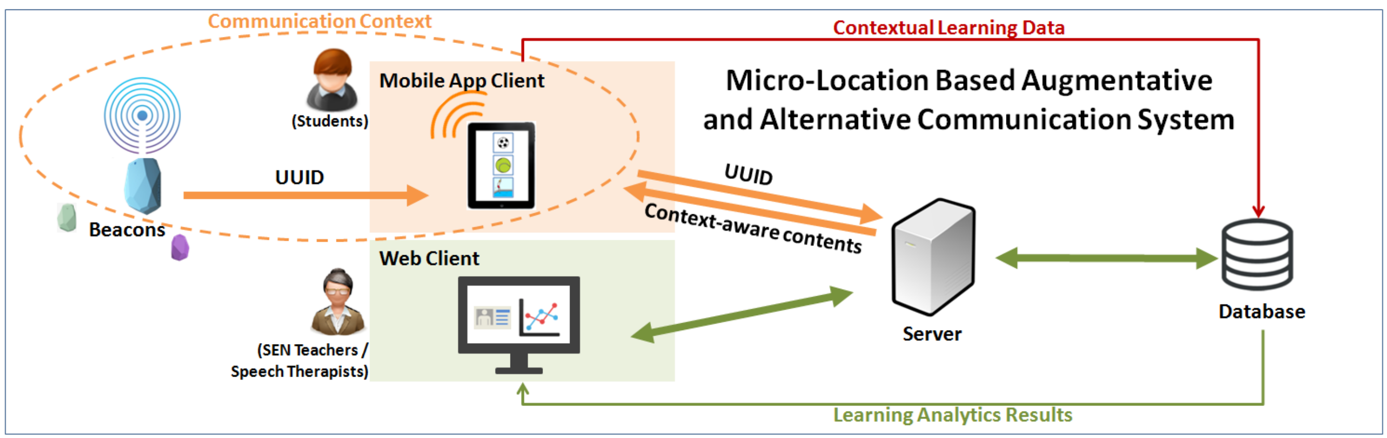

Figure 5: Overview of micro-location based augmentative and alternative communication system.

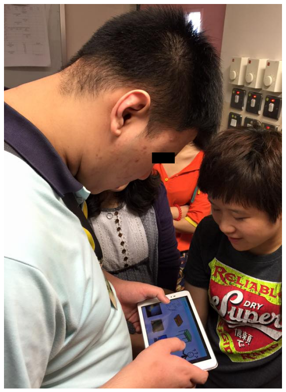

Figure 7: A non-verbal student trying our app with the support of the speech therapists.

Micro-Location Detection

Our system is capable of micro-location detection of a moving user who is walking inside the school building. This is achieved by the mechanism in which the beacons constantly emit the BLE signals which contain the universally unique identifiers (UUIDs). When the user enters the *geofance* of the beacons (which can be overlapped), the mobile device will receive the signals and determine the UUID of the nearest beacon, and forwards it to the server to obtain location-specific data (e.g. the room) to provide context-aware services.

Stakeholders Involvement, Field Tests, and Initial User Evaluation

The SEN teachers and speech therapists of the school had been involved since the early stages of system design. In particular, they participated actively in the UI design process through iterative UI prototyping.

We have conducted preliminary system tests at the school by placing the beacons in the canteen, the covered playground, and a classroom. Our app can display the context-relevant picture cards correctly.

We have also tested our system at the smallest room (as well as its adjacent room) inside the school building to ensure the proper functioning of the micro-location detection and ranging capabilities. We invited a non-verbal student (who is experienced in AAC app usage) to try our app (Figure 7). He was able to select a relevant symbol (a glass of water) to indicate that he was thirsty, and expressed that he liked the app by nodding his head.

Picture Cards Deployment and Personalization

Since the students are already familiar with the existing paper picture cards, the full version of our system will inherit the current set of symbols being used in the school's existing AAC practice. In particular, there are two types of communication symbols namely the context-related symbols and personalized symbols. Context-related symbols correspond to the picture cards that are currently displayed on the walls in different school areas (e.g. functional classrooms and canteen); which are the same for each user. Personalized symbols are specific to individual users, such as the snack (e.g. potato chips of a particular brand) which the student user particularly likes. In the full version of the system, a personalized learning profile will be maintained for every user at the server side, which records a personalized set of picture cards that are relevant to and has already been acquired by the corresponding student. The mobile app will automatically preload the context-related picture cards (e.g. a pencil and a book) according to the detected location (e.g. the classroom). It will also display the set of personalized picture cards according to the user's learning profile. To achieve UI personalization, the learning profile will also specify the number of cards to be displayed on the app interface (e.g. as 2 X 3 or 3 X 4 arrays) according to the cognitive and motor abilities of the user.

User Study Planning and Design

Two groups (one experimental and one control) of non-verbal students at similar motor and cognitive ability levels are invited to conduct a formal user study in the future semester. The experimental group will use our tablet for classroom learning, while the control group will learn with the original paper-based AAC means. Our user study will be guided by the longitudinal correlation model (Figure 8 on next page) which is extended from the cross-lagged panel correlation model

[15] (Figure 9 on next page) that takes the students' conditions (such as hearing loss and language gains) into consideration. This is particularly important to user studies in HCI in special education as students with SEN may suffer functional capacity deterioration along time. The correlation patterns will be informative and allows alternative explanation, such as the influence of app usage on communication and language level (measured with existing student assessment tools) along time. We will also refer to the fieldwork and experimentation design described in [3] and [7] for measuring the effectiveness and performance of our system.

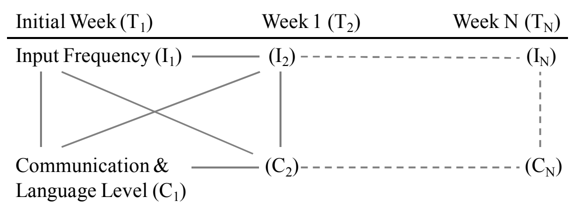

Figure 8: Model guiding our user study. The longitudinal correlation model includes three variables: time (T), input frequency (I), and communication and language level (C).

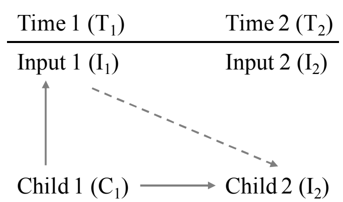

Figure 9: The original cross-lagged panel correlation model for evaluating the input frequencies (I) and language level (C) along time (T) [15]. Correlations can be concurrent (I1×C1) or lagged (I1×C2).

Discussion and On-going Work

As a breakthrough and novel feature over the existing AAC solutions, our AAC mobile client can detect the indoor micro-location of the user, and displays a reduced set of symbols that are directly relevant to the communication context of the user (with a level of accuracy within a few meters). This makes our AAC functionality more akin to the actual mechanisms in human communication, in which only desired concepts which are relevant to the communication contexts are preloaded (as preverbal intended messages) at the conceptualization stage before the formulation and articulation stages in speech production [11].

We continue to develop the system into its full version. In particular, we will implement the learning analytics functionality by incorporating the user study into system design. For example, the input frequencies will be recorded by the mobile app automatically. The communication and language level indices will be obtained from weekly student assessments to be input by the speech therapists or teachers via the web client.

Every student has a unique combination of areas of strength and areas that require additional support. We hope our current work can be one step in HCI towards inclusion and engagement for learner diversity.

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