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A Wireless Augmentative and Alternative Communication System for People With Speech Disabilities

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ABSTRACT An augmentative and alternative communication (AAC) device for people with speech disabilities is presented. This AAC system exhibits the advantages of two currently used systems: 1) usability of the communication boards and 2) natural oral communication of the electronic communicators. To improve comfort in use, robustness and versatility, the system is designed as two separate blocks linked by wireless communication via a wireless network of communication board sheets. The communication sheets, which are the interface with the user, are economical, simple to use, and scalable to adaptation of the number of symbols and the vocabulary of the individuals who use the system. The digital system (record/player system) controls the net, identifies the active sheets and the pushed symbols, and plays and records all sounds. This digital system can be easily replaced by other digital interfaces, such as computers, smartphones, or tablets, and can increase the function of the AAC with the possibility of using the Internet communication (emails and Skype, among others). The prototype has been evaluated in two special education schools, which are attended by children with severe motor disabilities with or without associated disorders and multi-deficiencies. Positive reviews from individuals who use the AAC system open the possibility of the system's use in both home and educational environments.

INDEX TERMS Augmentative and alternative communication, wireless communication network.

I. INTRODUCTION

Statistics Canada, US, UK and Australia say that approximately 1.3% of the population has complex communication needs and cannot rely on natural speech for communication [1]. This proportion has increased in recent years. Beukelman [2] lists the factors that have contributed to the increase in the number of individuals who require an augmentative and alternative communication system (AAC):

a) Improvement in the survival rates for children born with developmental disabilities [3].
b) The increased number of people with autism spectrum disorders (ASD) Lord et al [4] found that at 9 years old, approximately 14 % - 20 % of children diagnosed with ASD present little or no functional speech, that is, with daily use of five or fewer words.
c) The incidence of cerebral palsy. Approximately 95% of children with cerebral palsy who have speech and/or language limitations might benefit from using an AAC [5].
d) Finally, the increased life expectancy for the population has usually resulted in an increased number of older adults with language impairments, hence requiring some sort of AAC support [6].

These factors illustrate a wide variety of intellectual abilities and stages of development. Therefore, AAC systems must be flexible to adapt to people with different characteristics such as age (elderly and children), speech/intellectual ability (advanced vocabulary or limited) or familiarity with new technologies [7].

Currently, AAC systems based on pictograph boards (communication boards) with or without electronic voices are available along with other traditional systems such as sign language, Morse code or traditional spelling for people with speech disabilities. Up-to-date commercial AAC systems include aided systems that require external devices such as

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communication boards or books of line drawings, words, and/or the alphabet as well as computer-based technologies with voice and/or print outputs [8].

The first option to fulfill the requirements of an AAC system is based on communication boards. These boards consist of printed symbols or pictures that contain the vocabulary that an individual needs, which require users to change the picture whenever they need to make an item or activity. This solution is both intuitive and low cost while allowing voiceless communication using words, ideas or even simple sentences. However, the main drawback of this system is that individuals who are not familiar with the pictographic system must learn the meanings of the symbols. If written words or sentences accompany the symbols, this problem is reduced, but the need for proximity to read all of the words raises another problem. This requirement limits the possibility to engage in a conversation with AAC system users or even incorporate those individuals in any conversation. For this reason, the use of this system is preferred in a familiar or usual environment where an external assistant is not needed.

To overcome these limitations, an approach based on electronic communicators has been proposed to complement the communication boards by adding digitized voice outputs, which results in an increased degree of sociability for people with speech disabilities [9], [10]. Such a feature eases the intervention in conversations with people who are not familiar with the system of pictographic symbols, increasing the communication quality and improving the user's communication skills. These systems use specific platforms or software running on standard digital personal devices such as a personal computer, tablet or smartphone. Commercially, systems consisting of an electronic communicator are based on a surface where symbols and an electronic voice reproducer are placed in the same device, creating lower cost products that are often fragile or that offer little flexibility [11]. There has been increased interest in the use of portable media players and smartphones such as speech-generating devices (SGD) with synthesized or digitized speech [12] due to the increased portability, high peer acceptance and convenience. Proloquo2Go, an AAC application for the iPhone, iPod Touch, and iPad that includes over 8,000 Symbolstix symbols, has received much attention from the media. Studies about the utility of the iPad as a alternative communication solution generated inconclusive results [13]. For this reason, and depending on the environment in which the users are, people with communication disabilities can choose a combination of both solutions, as shown in figure 1, looking for the advantages of both of the approaches previously described (table 1).

In this work, we present the design of a new, simple and low-cost AAC system that combines the advantages of the systems described in table 1. With this idea in mind, we designed a wireless network of symbol sheets connected to a main digital controller that identifies the active sheets and plays the corresponding sound of the selected symbol. In this way, the user will have an interface similar to the platform-based ones while retaining the benefits offered by electronic communicators. The expected outcome of this design is to improve, as much as possible, the communication skills of people; hence, this new system will offer versatility and adaptability to the intellectual level of the user.

FIGURE 1. Example of use of both commercial CAA systems (UTAC courtesy).

TABLE 1. Advantages and disadvantages of the two main AAC approaches.

º	Advantages	Disadvantages
Communication Boards	➢ Easy to use. ➢ Easy handling. ➢ Robust.	➢ Need to know the pictographic system. ➢ Difficulty in communicating with people who do not know pictographic system. ➢ Limitation to participate in talks.
High-tech Communication Devices	➢ People can talk to people who do not know their pictographic system. ➢ People can participate in social situations such as group discussions, class, ... ➢ Users can interrupt a conversation to communicate their needs. ➢ Communication is more naturally driven. ➢ The person has more feedback and is more aware of its communication process. ➢ The person has a model for speech and is more likely to develop his own speech with this model.	➢ Weight and size. ➢ Technological dependence. ➢ Difficulty in having a broad vocabulary because of the need to manipulate multiple complex pages ➢ Difficulty in handling. ➢ Fragility. Problems with the beats. Many people with communication problems may also have physical or behavioural problems. ➢ The cost can be high.

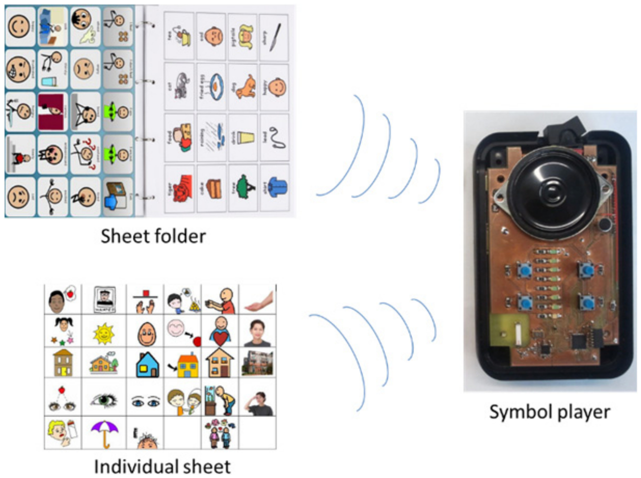


FIGURE 2. General architecture of the system: individual or folder sheet and symbols player.

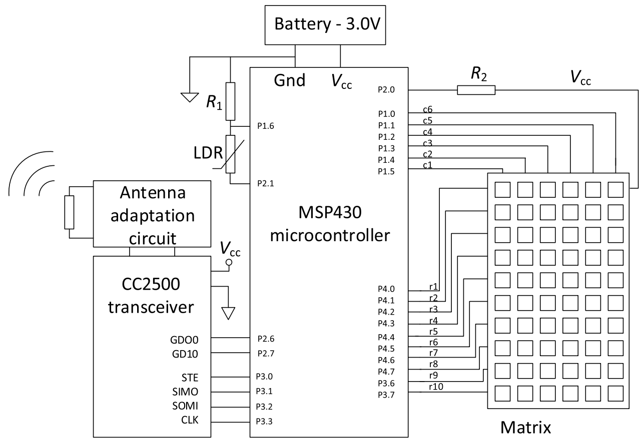


FIGURE 3. Design of the electronics in communication sheets that included a voltage supply system, an antenna adaptation circuit, a CC2500 transceiver, an MSP430 microcontroller and the selection matrix.

II. SYSTEM DESIGN

The AAC system design consists of two physically separated blocks, the vocabulary communication sheets and the symbol record/player, which are both linked by a wireless communication protocol. Considering the potential educational applications for the AAC, direct interaction is thus possible either with individual sheets or with groups of sheets organized in folders in a more intuitive manner (Fig. 2). A further benefit of this scheme is the reduced interaction with the player; hence, people with motor problems would not need to manipulate large objects, and this architecture is therefore easier for these individuals to use.

A. COMMUNICATION SHEET

Communication sheets (CSs) have a look similar to currently used communication boards and similar to a paper classifier. In this first prototype, these sheets are A4 sized and are transparent on one side. Nevertheless, this size is not a restriction to accommodate different sizes of symbols of the communication panels printed on paper. Each sheet can have a maximum of 60 boxes with independent messages that might be grouped to form larger boxes (5×3, 2×2 and 2×1), especially for individuals who use the system with reduced vocabulary or who need larger images. Different combinations of boxes can also be used to denominate free mode. Each player can accept a maximum of 256 sheets so that the vocabulary can be set from 2 (2 symbols per sheet) to 15,360 symbols (256 sheets – 60 symbols per sheet). The sheets accept any type of symbol that represents a word, sound, phrase or feeling and can be freely designed or selected from different sources such as those developed by Lessonpix [14], Sclera Symbols [15] or the CACE project [16].

These sheets are battery powered and include an electronic control and a communication system (Fig. 3) to make the activation of the system and the transmission of information transparent to the user. Low cost is a desirable feature to make scalability (increasing the number of sheets) cheap. In addition, the power consumption of the design must be very low to reduce the recharging needs, as happens in the majority of systems for medical applications [17]. To reduce the cost of production and achieve robustness and false positive rejection, the sheets are made of rigid materials, and a selection matrix is placed on a 1-mm PCB board FR4, which is not affected by external factors such as dust or water. The electronic system of the sheets is placed on its left side and is composed of four elements: the wireless communication systems, the microcontroller, the activation control circuit and the battery (Fig. 4).

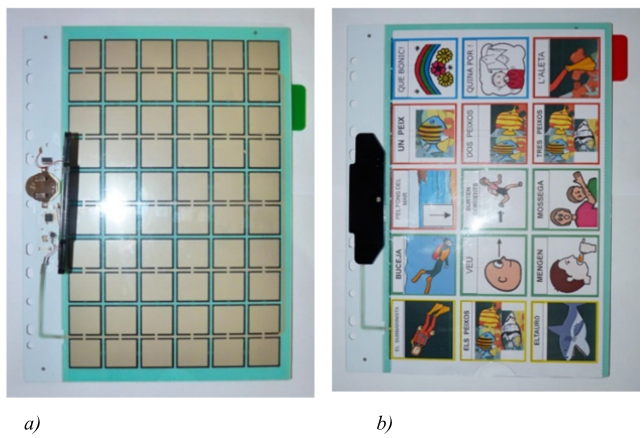


FIGURE 4. Example of A4 sheets with the electronic system on the left size. a) PCB design and placement and b) example of an arrangement 5×3 symbols.

Due to its low consumption, low cost and high distribution, we have chosen the Zigbee technology (CC2500 RF transceiver, Texas Instruments) to implement the wireless communication between the sheets and the player. The wireless protocol used is SimpliciTI (proprietary protocol of Texas Instrument) and works in the free band of 2.4 GHz, allowing a coverage range, in this application, from 1.5 m to 10 m. In addition, the implemented protocol only uses three data bytes of payload from the 20 possible; the first byte is a sheet identifier used for synchronization with the player, the second one contains the pressed symbol identifier, and the third one indicates the battery level.

The CC2500 is controlled by an MSP430F2274 microcontroller unit (MCU). Typically, to reduce digital consumption a Dynamic Power Management (DPM) is commonly used (wake-up methods), consisting on a sensor system remaining in different sleep times effectively reducing the consumption as long as the sleep time is much bigger than the active stage time. Another method commonly linked to the DPM is the Dynamic Voltage Scaling (DVS) for digital consumption reduction. While DPM reduces the overall consumption using low power modes, it is possible to have an additional energy saving if in the active stages the parts of the microcontroller not used are switched off. A part from the previous alternatives, the bibliography offers other less common solutions for digital consumption reduction, as including optimal synchronization of the communications or optimizing preprocessing operations. All these solutions have been used in the design of new AAC system. In this design, the MCU works between two modes: sleep mode (2 μA consumption) and transmission (active mode, 3 mA consumption). To select these modes and avoid false positives (false selection of symbols), there are two activation control signals. The first signal comes from a general-purpose light-dependent resistor (LDR) that detects an active sheet; if the sheet is placed below the others, that sheet is considered inactive. The LDR was chosen because its power consumption is less than 1 μA when in the dark (inactive) condition. The second activation signal is the symbol pulsation, which is enabled only when the LDR detects an active sheet.

In sleep mode, the battery level is supervised every 10 minutes, and this information is sent together with the transmission symbol. The active sheet signal is polled every 100 ms, and if an active sheet is detected (programmable activation threshold, 50 lux by default), the microcontroller starts the communication with the record/player system. In this situation, the selected symbol generates an MCU interrupt and the transmission mode begins.

B. SYMBOL RECORDER/PLAYER SYSTEM

Although any portable commercial system (smartphone, tablet and the like) might perform as a sound player system, our design includes an own-built symbol recorder/player (SRP) system located within a small housing to make the system easily portable, for example, on a belt or on a wheelchair. Each player can handle a maximum of 256 communication sheets simultaneously, an important feature with respect to education applications that require a number of students working simultaneously with only one instructor's player, as occurs in collaborative learning methods.

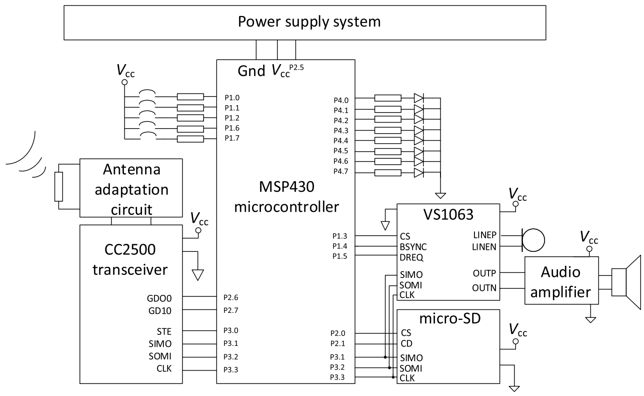


FIGURE 5. Design of the SRP. This includes a supply voltage system, an antenna adaptation circuit, a CC2500 transceiver, an MSP430 microcontroller, a microSD, a VS1063 audio decoder and an audio amplifier.

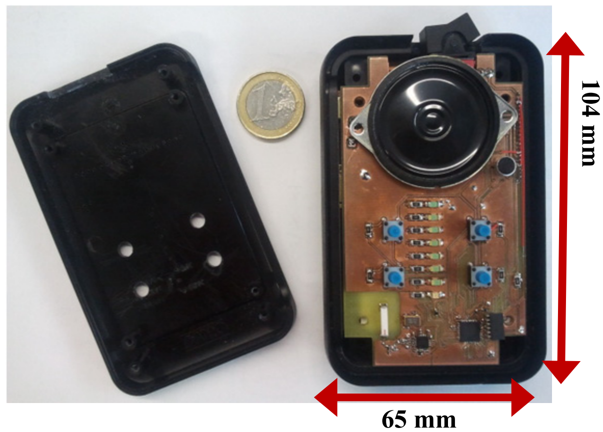


FIGURE 6. Physical design of the symbol player.

The system must have a similar structure to a portable sound reproduction but with three key differences:

a) The player is controlled by the signals coming from different sheets through the wireless link.
b) The audio power output should be similar to that of a commercial AAC system (1.0 W to 1.5 W).
c) The recording of sounds can be associated with one or more symbols (depending on the selected mode group of cells).

Fig. 5 depicts the SRP design. Symbosl are stored in a microSD card, and they are further decoded by the VS1063b monolithic audio decoder. This system also contains a CC2500 RF transceiver for the wireless RF link and an MSP430F2274 MCU to perform all of the necessary functions (playback/record of symbols, wireless communication, etc.). To minimize the size, optimize the battery life, minimize distribution problems and cost, typical lithium batteries such as those used in mobile phones or portable systems are selected. Regarding the physical aspect, a form factor similar to that of current smartphones but thicker (104 × 65 × 24 mm) was chosen, as observed in Fig. 6.

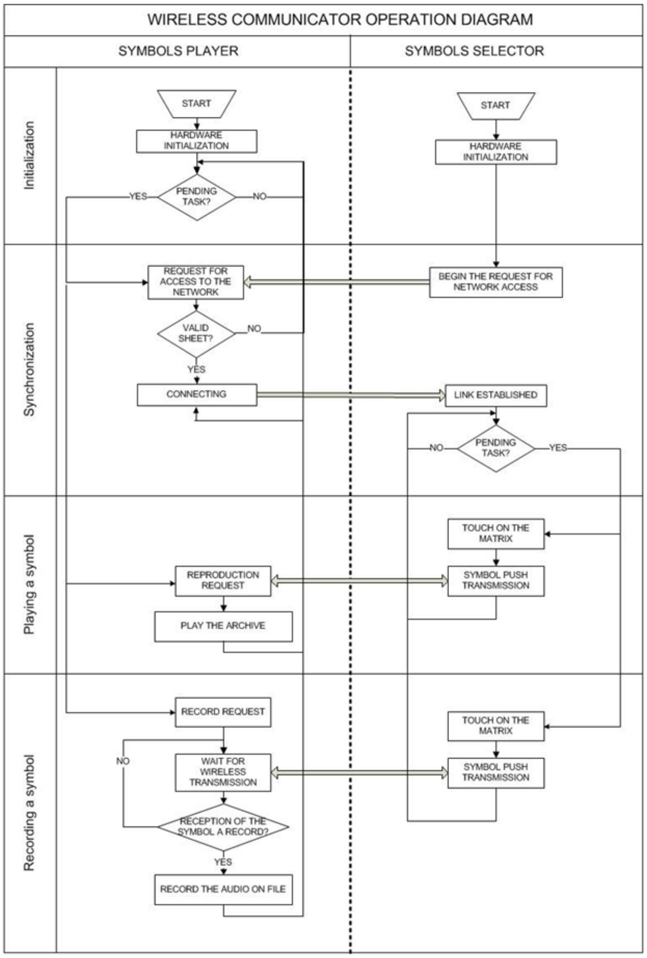


FIGURE 7. Flow diagram of the Symbols record/player system recording process.

C. COMMUNICATION PROTOCOL

The flow diagram of Fig. 7 explains the operation of the wireless communicator. Four functions are performed: initialization, transmission, symbol recording and symbol playing. After successful initialization of the SRP, the system sets itself to listen mode, waiting to process any sheet request (network access, symbol play or symbol record) or to handle the interface buttons (mode change, check the remaining battery level, reset the device or increase or decrease the audio volume). In parallel, every 10 minutes, the system checks the battery status automatically.

At the beginning, the CS also initializes its hardware (microcontroller and wireless communication). If the process has been successful, the sheet searches any symbol recorder/player in range and requests network access.

After five unsuccessful attempts, the sheet enters into sleep mode until the user presses on the matrix or the LDR activates the sheet. For these latter actions, the sheet tries to synchronize again with any player symbols. If, however, the SRP receives a request for access to the network (and had been previously synchronized with the CS), it establishes the wireless link between the devices. When a link is established, the communication sheet will remain in sleep mode, waiting to transmit a symbol (matrix pressed) and checking the status of the LDR (every 100 ms) or checking the battery state (every 10 minutes).

Each time the user presses on the matrix, it sends a request message to play the corresponding symbol. The SRP receives the request; it checks the audio file and plays the requested sound that corresponds to the symbol. An acknowledge (ACK) message is used in receipt of the player request. If the CS does not receive the ACK message, the player is not operative and would start the process of searching for a new SRP.

The recording process starts when the appropriate interface buttons on the recorder are pressed. The user must click on the cell of the selector matrix symbols that will correspond to the recorded audio or, in the case of groups of fixed cells, press successively on all of the cells that the user wishes to combine into a single symbol. In the latter case, for each new symbol that is added to the selection by clicking on that symbol, the player makes a short beep sound to indicate correct reception. When the user finishes the selection of cells, the SRP produces a long beep (after waiting two seconds without receiving any new selection cell), and all LEDs are activated, indicating that the device is ready. At this moment, the user can record the symbol. After the audio recording, all LEDs of the SRP will turn back on for one second to indicate that the process has been successful.

III. ELECTRICAL CHARACTERIZATION AND FUNCTIONAL TEST

The designed system has been characterized in the laboratory to verify compliance with technical specifications (consumption and autonomy, rate of communication failure, operating range, power audio output, etc.). In addition, the AAC has been used in a school for people with disabilities to assess the real usability of the system and to validate the functional design specifications. These tests are not to perform an in-depth study of a particular application of the AAD. The objective has been to evaluate the system in different real situations and with different users and supervisors to optimize the AAC design for future uses.

A. ELECTRICAL CHARACTERIZATION OF THE SYSTEM

1) CS POWER CONSUMPTION

The power consumption of the CS has been measured for different operating modes. For this purpose, a series low-value resistor has been placed in the output to the battery to measure the consumed current indirectly by means of Ohm's law and the voltage drop recorded by a digital oscilloscope (Fig. 8). The values thus obtained are used to yield the current consumption profiles for the different operating modes: 1) system initialization, 2) wireless connection with SRP, 3) transmission (symbol pressed detection, verification of the link with SRP, message transmission) and 4) other functions. Table 2 lists the most relevant results, where the average values are the results

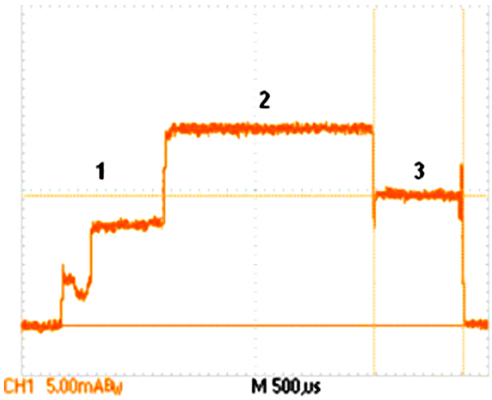


FIGURE 8. Symbol transmission consumption.

TABLE 2. Results of the communication sheet system characterization.

Procedure	Consump	Activity Time	Average Consump	Daily Time	Daily Average Consum
Initialization and Connection	2.2 mA	580.0 ms	5.2 mA	688.0 ms	4.3 µA
	21.0 mA	108.0 ms			
Transmission of a symbol	5.0 mA	140 µs	16.5 mA	4.4 ms · 2,000	
	3.6 mA	200 µs			
	11.0 mA	760 µs			
	21.2 mA	2.3 ms			
	14.0 mA	980 µs			
LDR state	150.0 mA	1 µs	150.0 mA	86.4 ms	
Battery state	3.2 mA	232 µs	3.2 mA	33.4 ms	
Rest	2.4 µA	86,390.63 s	2.4 µA	86,390.4 s	

of weighing the procedure consumptions by their execution times over one typical day of use, which is equivalent to 2,000 pressed symbols.

Experimental measurements demonstrate the low power consumption of this design, achieving only an average consumption of 4.3 μA. Two factors explain this low consumption. First, the device is in sleep mode most of the time, consuming only 2.4 μA. Second, the low consumption during a symbol transmission is due to the low-power wireless communications technology used, which is quite standard compared to other available technologies. In addition, the time used for each transmission is reduced to only 4.4 ms. In the case of the designed prototype, we used a 100 mAh lithium battery of providing a lifetime of 2 years and 239 days. Therefore, due to the battery type, we have an autonomy greater than one academic year (nine months, estimated lifetime); hence, the battery would not need to be changed during an academic year.

TABLE 3. SRP times and consumption in the final system.

Mode	Time Average	Consum Average	Daily Time	Daily average consum
Initialization	262 ms	19.8 mA	1.30 s	77.1 mA
Listen mode	23,698.70	29.2 mA	23,698.70 s	
Play mode	2.23 s	305.4 mA	2.55 s · 2,000	
Rec mode	2.25 s	60.1 mA	2.25 s	
Battery State	232 µs	3.2 mA	11.1 ms	
Battery State and volume control	450 ms	49.7 mA	1.35 s	

2) SRP POWER CONSUMPTION

The SRP is designed to work with rechargeable batteries with a minimum autonomy of one day of use. Additionally, the batteries must be as small and cheap as possible.

We have characterized the power consumption of this system in a similar way as that made with CSs as well as for different operating conditions: 1) initialization (delay, hardware initialization, sleep mode activation); 2) listen, play and record modes; and 3) other functions. The power consumption and the activity time of the usual procedures have been assessed for a typical day of operation with 2,000 pressed symbols (acceptance of the communication sheet in the network and battery monitoring every 10 minutes), and the results are shown in table 3. These results yield a system autonomy of 17 hours for a typical lithium battery of 1350 mAh, requiring only one daily recharge.

3) PROBABILITY ESTIMATION OF FALSE NEGATIVES IN THE DETECTION AND TRANSMISSION OF SYMBOLS

We have characterized the incidence of false negatives in symbol transmission for two situations: transmission from an individual sheet and transmission from a sheet in a folder that is typical in an educational situation. Additionally, the influence of the transmission antenna alignment has been studied. The results are shown in table 4.

As observed in table 4, the worst situation occurs when the detected sheets are inside a folder (typical situation in the classroom). In this circumstance and with a correct alignment of the transmitting antenna and the folder metal rings, we obtained error probabilities below 0.03 % for distances down to 1 m. This result means that it is necessary to repeat one press every 4,500 pulses, or less than one press every two days. If the distance is increased to 2.5 m, the need to repeat a press increases to 1 press every 430 pulses (four each day).

4) OUTPUT AUDIO POWER

We measured the output power audio amplifier (LM4871). The test was performed using a 1 kHz sinusoidal signal.

TABLE 4. Error rate pulsation/transmission of symbols in the final prototype.

SITUATION	COVERAGE	POWER	MESSAGES SENT	FAULT	P.ERROR (%)
Individual Sheet	15 cm			3	0.006
	100 cm			5	0.01
	250 cm			105	0.21
Sheet in folder Antenna aligned with the folder guides	15 cm			18	0.036
	100 cm			55	0.11
	250 cm	1 dBm	50,000	5150	10.3
Sheet in folder Antenna shifted to the center of the folder guides	15 cm			10	0.02
	100 cm			11	0.022
	250 cm			116	0.232

The user can adjust the volume, controlling the output end. Powers up to 1.2 W can be selected with harmonic distortions lower than 1%.

B. FUNCTIONAL TESTS

1) TEST PROTOCOL

The prototype device was evaluated in user trials designed to assess the process of configuring the AAD device for a new user as well as the performance of the device in real communication situations. These functional tests of the communicator were performed in two special education school in Barcelona. Nadis school [18] and l'Arboç school [19]. Both school work with children ranging in age from 3 to 21 years with severe motor disabilities, with or without associated disorders and multi-deficiency. In all of them, communicative function and interaction with the environment are seriously affected and personal autonomy at different levels (travel, cephalic control, swallowing, handling ...)

The tests were performed with eight children (from 7 to 17 years in age) and four supervisors. Table 5 summarizes the characteristics of the participants. All of the participants had previous experience in the use of AAC communication systems. The users performed different sessions with the device over three weeks.

The evaluation consisted of different stages, each of which studied a particular aspect of the configuration and usage of the AAC. An observer took notes of the comments and opinions of the people involved in the experience at all times, and after the completion of the test, a satisfaction questionnaire was filled in by the supervisors (table 6).

The first stage was a 45-minute meeting between two developers of the AAC system and the two supervisors.

TABLE 5. Participants in the user tests.

Nadis school	**Age**	**Description**
Supervisor 1 and 2		They belong to the teaching staff of the Nadis school. Accustomed to customize and use different types of communicators in people with different disabilities.
Children 1	7	Dysplasia of the right cerebral hemisphere with an arachnoid cyst and hematoma diencefalic the right temporal lobe. Cerebellar hypoplasia with involvement in both hemispheres and vermis I. Right anophthalmia.
Children 2	14	Tetraparesis for congenital encephalopathy and handicapped.
Children 3	16	Tetraparesis for perinatal fetal distress and delayed maturity. West syndrome.
Children 4	17	Microcephaly, congenital encephalopathy and motor disorders (right hemiparesis). General delay especially in the oral expressive language level (playing vowel sounds) and communication.
L'Arboç school	**Age**	**Description**
Supervisor 3 and 4		They belong to the teaching staff of the L'Arboç school. Accustomed to customize and use different types of communicators in people with different disabilities.
Children 5	10	Cerebral palsy. Spastic - dystonic tetraparesis. Advanced level of verbal comprehension but impossible oral expression. Normally uses pictograph boards communicators system.
Children 6	11	Cerebral palsy. Spastic - dystonic tetraparesis
		with significant axial hypotonia. High oral comprehension but unable of oral expression. Normally he uses pictograph board communicator systems.
Children 7	15	Psychomotor impairment due to intrapartum hypoxia with Choreoathetosis/Spastic tetraparesis. Emotional contact and relationalship preserved. Level of understanding preserved but unable oral expression. Normally she uses pictograms board as communicator system.
Children 8	5	Psychomotor impairment due to extreme prematurity. Spastic tetraparesis. Emotional contact and relationalship preserved. Verbal comprehension preserved with possibility of oral expression. Uses augmentative communication in order to maximize communication, speech and knowledge of languages.

In that meeting, those responsible for the AAC presented the context of the project and the stages to follow during the test. During this stage, usage scenarios and the definition of the vocabulary to use were discussed.

In the second stage, an instructional video was played to describe in a simple and clear way the operation protocol of the entire system (CS and SRP). The video showed how to

TABLE 6. Satisfaction questionnaire after the completion of the user's tests.

➢ **About the tutorial video:**
✓ Easy or difficult to understand?
✓ Useful?
➢ **About the technical material:**
✓ Easy to understand?
✓ Useful?
➢ **About the recording symbol processing:**
✓ Easy to play? Do you think is hard to do the process?
✓ Easy to explain to others?
✓ What has been the most complex?
➢ **About system components:**
✓ Attractive
✓ Weight
✓ Manageability
✓ Robust
➢ **Global:**
✓ Do you use it?
✓ Do you recommend it?

perform basic tasks such as detecting if a sheet is active or not, the configuration of the templates or the process of recording a symbol. Additional printed technical manuals were also provided. These resources were the only instructions for operating the device during all of the tests. In the following stages, the use and configuration of the AAC device was performed by supervisors and subjects with no technical oversight by the designers.

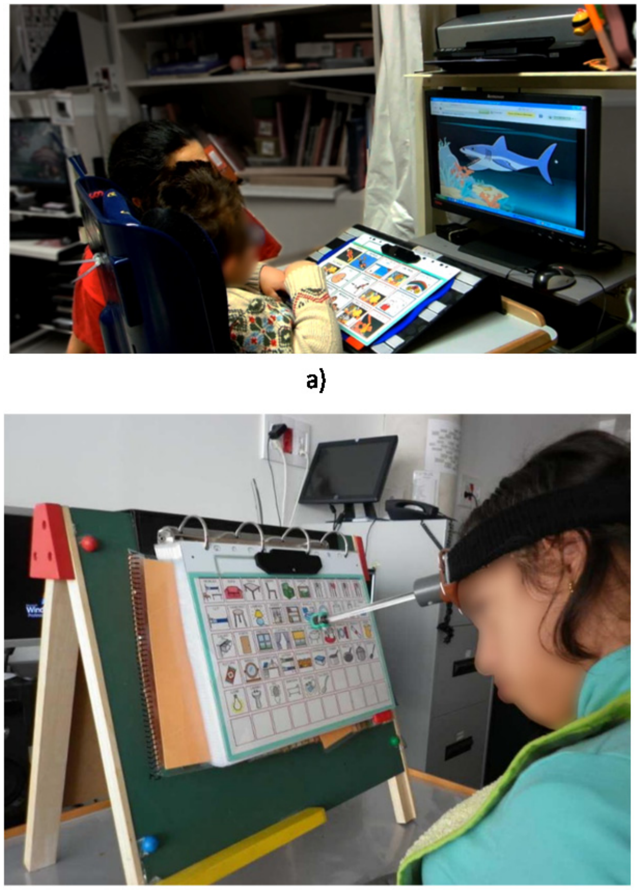
The third stage consisted of the tests in different educational sessions. Usually, individual tests were performed: a) informal communication and b) learning new vocabulary and themes in sessions with the AAC communicator and video support in TV (Fig. 9). Cooperative use of the system with one SRP and the used CSs distributed between two students was also studied.

The last stage was a face-to-face meeting with supervisors in which the conclusions extracted from the tests and the results of the satisfaction questionnaires were documented.

2) RESULTS OF THE FUNCTIONAL TESTS. ADVANTAGES AND LIMITATIONS OF THE DESIGNED SYSTEM

From the supervisors' feedback in the last stage, the following conclusions can be drawn:

- ➢ The device has generated great interest among educators who are accustomed to working with children showing different disabilities and who tend to use digital systems such as tablets or laptops.



a)

b)

FIGURE 9. Picture of one of the individuals who use the AAC. a) Children 1 from Nadís school and b) children 8 from Arboç school.

- ➢ Users were able to use the AAC system after a short introduction in a very intuitive way.
- ➢ Weight and manageability are good and resemble that of communication boards.
- ➢ The wireless communication feature facilitates the system's use. Furthermore, as users only use the CSs, adapting the AAC to different educational sessions and environments has been easy and positive.
- ➢ In some cases, protection systems, such as the introduction of the sheets into folders, have been suggested to provide the device with more robustness.
- ➢ The process of recording and erasing should be easier. Additionally it should be possible to either erase and record again a symbol individually or delete all symbols simultaneously.
- ➢ The supervisors have suggested the use of the AAC system as a device dedicated to the development of specific activities rather than as technical support used by a person to communicate at different times in any place. In this direction, the possibility of several students using the system cooperatively has been valued as an attractive novelty that allows new teaching methods.

- ➢ Supervisors suggest the possibility of adapting sheets to panels, and hanging them on the wall to be used daily in the classroom. Timetables, notifications or the weather may be the main topics of the panels.
- ➢ The feedback highlights the versatility of other commercial products on the market, such as tablets or laptops, as opposed to the commercial communicator presented that only allows augmentative and alternative communication. For this reason, the possibility to connect the sheets to tablets or laptops is very attractive for persons with experience in these digital platforms. This sheet-wireless network, where the tablet, the laptop or mobile phone performs controls, opens the possibility to introduce new communication systems, such as those based on e-mails, Skype or direct voice communication in smartphones with the same interface. This ability would solve a serious problem for people with disabilities such as the need to learn to control different interfaces when using different devices.

IV. CONCLUSION

We have presented a new AAC system design and architecture intended to solve the limitations of available commercial systems. Our design has very low power consumption and is based on low cost components, allowing a low production cost and thus making the system accessible to a larger number of individuals. The separation between the processes of detection and reproduction of the symbols (*CS* and *SRP*) favors the modularity and scalability of the system, and the wireless communication increases the comfort of use and adaptation to the mechanical abilities of the potential users. The *CS* is designed to be light, flexible, robust and simple with an appearance similar to a symbols page and can be sorted into folders for an improved ease of use. The electronic circuit is designed to be very small and with very low power consumption, allowing months of use without battery replacement or recharging. The high level of modularity makes it easy to replace the player block with another type of voice interface such as a phone or even directly access the Internet. Moreover, this network of communications sheets might act as a human interface between the user and a tablet, laptop or smartphone. Additionally, the system allows multiple persons to share the same symbol player. This feature is relevant for special education schools where each student might have their own group of communication sheets, each with its own personalized vocabulary, while requiring only a single player for each group/class of students or property such as the school or classroom that required a set of specific vocabulary sheets.

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