A Palmtop Based Modular Distributed Architecture for Vocational Integration of Intellectually Disabled People

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***Resumo*- Nesta comunicação, é feita uma breve descrição sobre aspectos de uma arquitectura modular e distribuída adoptada no desenvolvimento de um sistema baseado num palmtop para apoio à realização de tarefas complexas, por parte de pessoas com deficiências intelectuais profundas, em locais de trabalho integrados. São abordados, em particular, os aspectos modulares de implementação, o protocolo de comunicação desenvolvido e os respectivos enquadramentos com as especificações funcionais do projecto. Este trabalho insere-se no contexto do projecto europeu VICAID (Vocational Integration through Computer Assistance for Intellectually Disabled People).**

***Abstract*- This paper reports briefly on the modular and distributed architecture adopted for the development and implementation of a system prototype based on a palmtop computer, aiming the support of complex task routines performed by people with severe intellectual disabilities. In particular, modularity of the adopted solution and the wireless communication protocol are shortly described, together with their interrelation with the functional specification of the project. This work is part of the European project VICAID (Vocational Integration through Computer Assistance for Intellectually Disabled People).**

I. Introduction

Within the TIDE programme (Technology Initiative for Disabled and Elderly People), the VICAID (Vocational Integration through Computer Assistance for Intellectually Disabled People) project aims to develop and evaluate a comprehensive system based around the use of Palmtop microcomputers as prosthetic, teaching and support aids. The system is supposed to support people with severe intellectual disabilities to perform complex work routines (tasks) in integrated work settings. This is done by providing a sequence of instructions, in the form of visual prompts, as response to users keyed entries, while monitoring user performance and providing automatic prompting for both users and their supervisors. Initial phases of the project involved the definition of a preliminary *Reference model* [1, 2] gathering all human factors and establishing their interrelationships with the technical constraints and possibilities. This, in turn, resulted in a first version prototype definition [3].

II. Functional Specification

Based on the general goal of the project, an analysis of the functions that the system should provide has been performed [4, 5]. Accordingly with this analysis, an arbitrary complex task should be divided into several steps and each one of these steps should have a specific instruction (e.g., "open the dishwasher door"). The set of instructions related with one task should be sequentially delivered to the user, who should only need a single step command to require the next instruction: the user will be expected to push always the same key to ask for the next instruction in the sequence.

Each instruction should be related to one or more prompts that could take a visual, an audible or a mechanical form: the visual prompts could be an image or an icon displayed in the system screen and complementary information such as flickering lights; the audible prompt could be a beep or a sound pattern; finally, the mechanical prompt should take the form of a vibratory unit attached to the subject.

Each instruction should be composed not only by the prompting information but also by a set of timing parameters related with each step: the minimum execution time, the expected execution time and the maximum execution time. The interval between two user requests (the period of time to perform a particular instruction) should not be smaller than the pre-set minimum execution time neither longer than the expected execution time. The system should prompt the user if neither the minimum nor the expected execution times are respected. Furthermore, another prompt should be presented if the user exceeds the maximum execution time, which means that he/she is not in condition to proceed correctly with the task.

Besides the user himself, who relies in the system to perform correctly any specific task, it is also necessary to consider the interaction between the co-worker and the system. The co-worker has the mission to supervise the work of intellectually disabled user. Therefore, the system should be able to alert (prompt) the co-worker whenever the user is not in the position to proceed in the task, either because he/she did not respect the maximum execution time or, if the system is aware of the user performance, whenever he/she has produced a wrong action.

On the other hand, and at pre-set intervals, a user request for the next instruction should not show the next prompt of the job task but rather a prompt indicating that the he/she should contact a co-worker to have a check on his/her work or to have reinforcement. Reinforcement, which takes the firm of a positive remark, a sticker or some other form of pleasant event, acts as an activator of the user self-esteem while keeping him motivated.

III. System Architecture

The first engineering approach adopted to cope with the previous functional specification was based on the development of a system composed by a Palmtop and several hardware devices with the required prompt facilities. All the devices were based on the same physical container, which included facilities for audio and visual prompting, audio recording and remote calling of a supervisor device. Several prototypes, resulting from this first iteration, were submitted to a laboratory evaluation performed by University of Leiden. This laboratory evaluation was carried out with 10 adult users with severe and multiple developmental disabilities, who were living in special residential centres or community homes with external supervision. The effectiveness of the prototype was compared to a control programme which involved the use of pictorial cues assembled in booklets.

Preliminary results [6] show that the system can generally help to ensure a high level of correct task performance, and that users who tend to be more inconsistent in their performance due to a higher degree of disability, may benefit more from it. Which results from the system ability to provide additional forms of prompts.

However, several aspects of the first prototype version proved not to be compatible with the set of requirements and practical issues which emerged from that evaluation. Considering both these results, the comments from the reviewers of the project, and also the conclusions from an internal workshop, a second iteration of the engineering effort was taken in order to establish the interrelationships of the aforementioned requirements with the different technical options and to retrieve the best possible solution out of the ideal one [7]

A modular physical and logical distributed architecture (figure 1) was considered to be the best solution to reflect an acceptable level of mutual accordance between the different requirements emerging from the *Reference model*. According to this approach the system should comprise an independent Palmtop subsystem and a set of Peripheral Interface Devices which will act as prompting devices for the final user and/or the co-worker. This approach also comprises the need of a communication infrastructure between the different subsystems.

In order to design the communication infrastructure three solutions have been evaluated: infrared, ultrasonic and radio based. In what concerns the two first options, the working direction is limited, and for optimal transmission conditions they demand small angles and the absence of

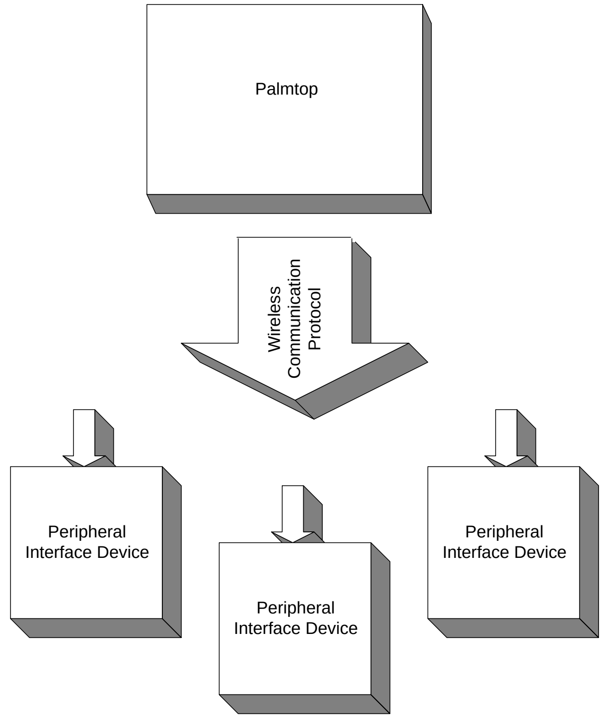

Figure 1. Modular distributed architecture

physical obstacles between each pair of communication points. Furthermore, these options are especially dedicated for fixed systems. Therefore, the option that has been selected was the radio based solution. This solution shows low sensibility to physical obstacles and physical characteristics of the work place environment. It works in several conditions independently of external noises (apart from interference from electro-magnetic noise in the same bandwidth), materials or layout of the work place, and is independent from the presence of external electronic systems, such as computers. Furthermore, the radio based solution has an easy implementation due the large availability of low cost the components, is omnidirectional and has adjustable range.

IV. Palmtop Subsystem

The core of the system is an IBM PC 110 Palmtop. This Palmtop has dimensions of 15.8 x 11.4 x 3.3 cm, weights 680g. It presents an Intel 80486SX (33 Mhz) CPU, 8 Mb of RAM, a 640 x 480 DSTN VGA screen (256 colours), several communication ports (infrared, serial and PCMCIA III) and is able to run any of the operating systems available for personal computers. The standard keyboard of the Palmtop has been replaced, for practical reasons by a conceptual keyboard, composed by large and strong key that will be pressed by the user to demand the next instruction. An extra small and hidden key is also provided to support co-worker interaction with the device. This two keys are all it takes, together with a multi-layer menu structure, to allow the co-worker/supervisor to fully control de device and all its functionalities, from task download to sequence control.

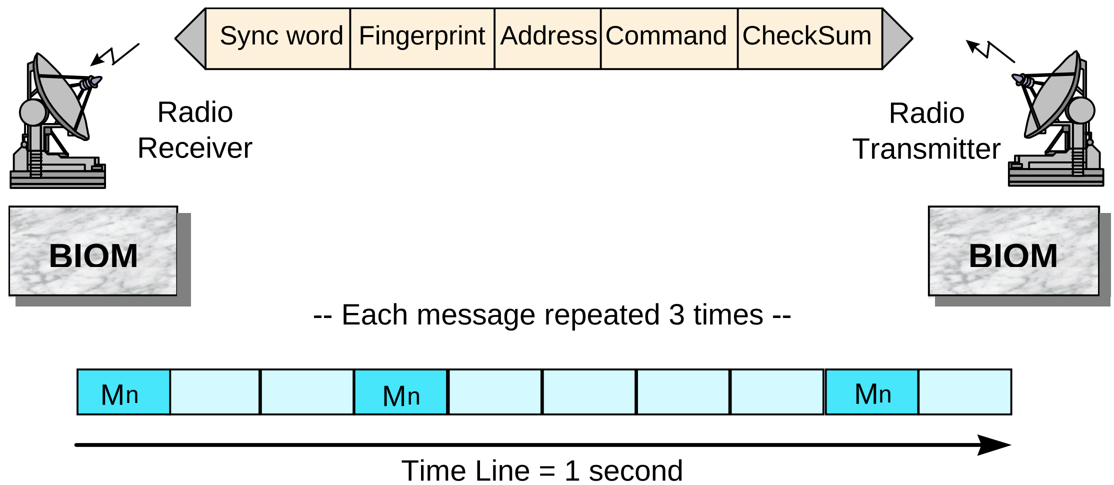

Figure 2. The wireless communication strategy.

V. Communication Infrastructure

A pair of radio Transmitter/Receiver modules, respectively the TX433SAW and RX-BC-NB guarantee the physical level of the remote communication, while the logical level is guaranteed by the Wireless Communication Protocol (figure 2). This protocol has been fully developed by INESC and aims the following main objectives:

- To take advantage of low power, low cost radio frequency Transmitter/Receiver standard modules.
- To assure transparent support for multiple Palmtops and multiple Peripheral Interface Devices in the same working environment.
- To support concurrent communication of multiple Peripheral Interface Devices using the same modulating frequency.
- To handle contention problems in a simple and effective way.
- To guaranty high reliability and data integrity from the receiver point of view.

Communication between two remote devices is established through the exchange of fixed size messages. Each message is locally encoded by a Manchester method which allows a full data clock recovery at the receiving end. This pre-coded message is then modulated by a 433 MHz frequency using a simple On/Off modulation technique prior to broadcast. Each message is further decomposable in the following five different fields:

- A synchronising word, which serves two different purposes. On one hand, to give the receiver local amplifiers a chance to restore their DC levels according to the available RF power. This will ensure correct retrieval of the data independent from the distance between emitter and receiver. On the other hand, and through the use of a fixed code pattern, to allow the receiver to phase synchronise the internal clock extractor algorithm.
- A fingerprint field. This is a special code word that identifies the protocol in use. This fingerprint is always different from the synchronising codes, and therefore also acts as a terminator for the Sync word long sequences. Furthermore, the Fingerprint can also be used to identify different types of messages.
- An Address field. Any specific subsystem has a unique address that identifies itself. The messages carry the address of the device that sends the message and the address of the destination device, which means that the messages are only decoded and interpreted by the subsystem to which it was first send to. However, a broadcast address could be used when a message should be received by more that one device.
- A data field. This field carries either a command or an event information.
- A checksum field. Used to cross verify the message integrity against transmission errors.

Each message takes around 30 ms to be send, and is only recognised and interpreted at the destination end if it arrives without errors. However, as the modulating frequency is the same for all the devices that share the same working space, some form of contention handling must be implemented. Taking into consideration that message transmission is a sparse event (even with several devices in the same working set, the average number of messages would be much less than one per minute), the following strategy has been adopted. Each message is send three times within the period of one second. Each second, on the other hand, is equally divided into ten time slots of 100ms each. The way these three repetition messages are distributed among the ten time slots is conditioned by a local five bit address that can be dynamically changed for any device. In this way, if any two devices, with different allocated time slots, try to send a message at exactly the same time, it is guaranteed that at least one of the three repetitions will be send and received unharmed at its destination. Therefore, up to 32 different devices can share the same physical space.

A. BIOM

Since the Wireless Communication Protocol is a common part of the overall system, it must be implemented in all the subsystems. Therefore, in order to assure a generic and open communication strategy, a common module has been defined. This module, called the Basic Input and Output Module (hereinafter referred as BIOM), has a main function of handling the communication between the several subsystems. However, the BIOM also includes other functions that are common to all the devices such as the battery management or the control of a serial link with the outside world. All those functions are controlled by a PIC16C73 which is a low-cost, high-performance, CMOS, 8-bit microcontroller that employs a RISC architecture and presents a broad range of facilities including an 8 channel ADC and a serial UART.

The BIOM is presented in all the Peripheral Interface Devices and it is also connected to the Palmtop to form what will be hereinafter referred as the Palmtop Platform. The BIOM of the Palmtop Platform receives, through a Command/Response Protocol implemented over a standard RS232 serial interface, the commands from the Palmtop and transmits them to the Peripheral Interface Devices via the referred Wireless Communication Protocol. The Command/Response Protocol is also used to report the Palmtop all the events received from the different Peripheral Interface Devices.

VI. PERIPHERAL INTERFACE DEVICES

Apart from the Palmtop Platform, a set of specific Peripheral Interface Devices has been specified and implemented. In short, these are the Audio Prompting Interface Device, the Mechanical Prompting Interface Device, the Visual Prompting Interface Device and the Co-worker Interface Device.

A. Audio Prompting Interface Device

For this particular kind of peripheral device, two different versions has been developed. For each concrete user one of the types will be selected. The two types of devices will have distinct functions: one will be carried by the users, typically clamped to his belt, and will reproduce the sound through an ear-piece. The other one, instead of reproducing the sound through an ear-piece, will be able to amplify and play back the sound through a loudspeaker. Being a static subsystem (assumed to be always located in the same place), this second version of the audio subsystem could even be powered from the mains line, therefore solving the autonomy problem. It would also provide an electrical signal output that could be fed to a standard audio equipment.

The interaction between Audio Prompting Interface Devices and the Palmtop Platform is assured by the above mentioned Radio Communication Infrastructure. Currently, a single frequency band at 433.82MHz, legally available in most of the countries, is being used for modulation of digital information. This frequency can not be used for voice. Therefore, instead of radio transmit the verbal prompts to the audio devices, a solid state audio recording/reproducing chip (ISD 2560 series) is installed in each Audio Prompting Interface Device together with a microphone. In this way, both tasks of recording and reproducing verbal prompts are performed by the audio prompting devices and are controlled directly from the Palmtop Platform, using the Wireless Communication Protocol.

B. Mechanical Prompting Interface Device

The Mechanical Prompting Interface Device acts as an alternative way of prompting the users, whenever the Audio Prompting Interface Device is not effective. That would be the case when a specific user, apart from his severe learning disabilities also suffers from deafness. In those situations, audio prompting will no longer be effective, and alternative ways of calling the user attention must be found. The developed Mechanical Prompting Interface Device produces a 5Hz to 20Hz vibrating movement that can be sensed by the user. Continuos vibration versus burst vibration are used to indicate various prompting situations, and can be selected through the commands of Wireless Communication Protocol send by the Palmtop Platform. The vibration is created by a small DC motor with an eccentric weight attached to its shaft. The container is similar to the ones used by Audio Prompting Interface Device with the ear piece.

C. Visual Prompting Interface Device

The Visual Prompting Interface Device is basically a prompting device providing a set of flickering lights used to visually alert the user. However, the VICAID consortium has agreed to postpone its utilisation since it has not been possible to develop a device which is, at the same time, strong enough to grab the user attention in all situations while being socially admissible to wear.

D. Co-worker Interface Device

The Co-worker Interface Device is a small box, carried by the co-worker on his belt, and activated through a command from the Wireless Communication Protocol whenever a reinforcement or corrective feedback occurs. The prompting consists of two different types of stimulus. An audio buzzer is turned on with a clear and sharp sound to grab the attention of the co-worker. At the same time, a tri-colour LED starts to blink with one out of three possible colours. The red colour indicates that a corrective feedback action should take place. The green colour indicates a reinforcement situation. The yellow colour, which is also available, is not being used for the current version and is reserved for future use.

After confirming which kind of action should be performed, the co-worker can shut down the device by pressing a single key located in the anterior face of the peripheral unit box. This will silence the buzzer and turn off the LED. At the same time, the BIOM will send a broadcast message indicating that the request has been acknowledge.

VII. Conclusions

Several prototypes are being submitted to evaluation under real working conditions. This evaluation is being conducted by the University of Leicester, University of Leiden and Faculdade de Motricidade Humana de Lisboa. For evaluation purposes a Monitor Interface Device has also been developed. This specific Peripheral Interface device is permanently listening to all the packets of the Wireless Communication Protocol on any specific site, and reports back to a host everything that goes on. This functionality can be extremely useful to keep track of user performance and to provide adaptive adjustments to the instruction sets.

The present implementation does not have any mechanism to provide the system with feedback from the user actions. The modular architecture of the system allows the development of devices for such purpose. The solution that is currently undergoing development will use small, optically encoded chips that will be placed near the objects the user must manipulate. The user will be trained to pick up this chips after each step (or a set of steps) and introduce it in a small bag with an optical reader on its top. This information will then be send to the Palmtop Platform, through the Wireless Communication Protocol, to indicate that the step associated with that chip has been performed. Knowing this, the Palmtop can determine if the correct step has been taken and decide what to do next based on that knowledge.

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