A Multimodal Network Board Game System for Blind People

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***Abstract*—Computer networks and especially the Internet have significantly influenced the diffusion of online games through remote opponents. However, the usual interfaces for board games are based on the visual channel. For example, they require players to check their moves on a video display and to interact using pointing devices, e.g., a mouse. Hence, they are not suitable for the people who have visual impairments. The present paper discusses a multipurpose system for board games that allows blind and deafblind people playing chess or other board games over a network. In particular, we describe a prototype of a special interactive haptic device to play online board games receiving feedback about the game on a dual tactile feedback.**

***Index terms*—Multimodal feedback, haptic device, blindness, deafblindness, board games.**

I. Introduction

A few years ago game-playing over the Internet was available only for rich communities, and online tournaments and championships of board games were unfamiliar concepts for most of the people. Year by year, the influence of the Internet on this kind of games is increased significantly. This has implied also side effects on the game itself. Regarding chess, for example, the availability of huge databases with the analysis of openings and endgames influenced the evolution of the game. Today, Internet board games and especially chess represent a great opportunity for players, trainers, professionals and they also have a strong impact on the younger generations of players. Furthermore, especially novices benefit from them, as they can learn and play the game at their convenience.

The interest in chess among blind people has increased in many countries during years. As a result, chess tournaments are hold by dedicated organizations such as the International Braille Chess Association [1]. However, blind people have no dedicated online chess association, likely due to the difficulty of using commonly adopted interfaces for online games.

In real life, blind people play chess or any other similar game thanks to special boards where cells have distinctive patterns so they can be recognized by touching them [2]. Pieces are designed to be easily distinguishable at touch, and in addition they can be steadily stuck in the center of a square to avoid that touching them alters the game configuration. Such a checker and chess set costs about 30$ [3]. Additional improvements [4] involve magnets under the pieces and a rigid metallic sheet beneath the playing surface, which enhances the stability of the game configuration when a blind person "reads" the board by touching it. However, these special boards are not easily interfaced with computer systems.

Conversely, the available software interfaces for remote games are designed only for sighted people, so that players interact using a mouse and a standard screen. Therefore, blind people should be provided with some extra tool providing a non-visual representation of the board. One possibility is to replace the screen with a tactile interface controlled by an electromechanical device, providing information about the actual configuration of the board and being capable to refresh it at each turn. Even though this could be implemented with an ad hoc electro-mechanical board, such a solution would not be efficient in terms of cost and complexity.

The alternative approach that we detail in this paper consists in the design of a natural interaction model, based on an innovative device, in which information about the content of the board is provided exactly in the same manner as in face-to-face situations. In more detail, we will discuss the design of a multipurpose device which provides blind and deafblind people with multimodal feedback in order to overcome all the barriers related to current technology. In our system, information is represented in a non-sequential mode: thus, visually impaired players are able to freely navigate over the board and access information about the squares as if they were touching real pieces. Several Braille-based devices could be suitable in order to implement this solution: in particular, there are mouse-like computer accessories having a character code member which enables visually impaired users to read text on a computer screen in Braille format [5]. Especially, the tactile communication system proposed in [6] is a low-cost input/output peripheral, shaped like a mouse, which consists of a haptic device having the purpose of both a Braille display and a sensor combined in a unique tactile information system. Input is acquired by sensing the pressure of a finger with a grid of 64 electrodes, while output is based on the use of low-voltage electrical current as a stimulus: mechanoreceptors' axons within nervous cells underneath the fingertip are excited with anodic or cathode current in order to generate different sensations on the user's skin.

Nonetheless, there are many challenges that need to be solved in order to achieve practical usability. First of all, the sensibility of this device to the current is different among individuals and it is subject to skin impedance changes that also depend on the environment and vary along time too. Moreover, such devices offer haptic feedback but do not provide any spatial information about the cursor position. Hence, there is no feedback received by the users when navigating over the screen apart from the movement of his/her own hand. As a result, visually impaired users are able to recognize the direction in which they are driving the mouse, but they are not aware of the exact location of the pointer on the screen.

To solve these problems, our implementation is therefore aimed at inserting the feedback for spatial information, which also needs to be properly elicited through a tactile channel. In the following, we will describe step-by-step the implementation details for our prototype design. The final implementation realizes a bi-directional feedback, and is therefore able to provide the users with spatial awareness of the placement of pieces over the board, at the same time making the behavior homogeneous for multiple users. We believe that this represents an original and significant step forward to fill the gap in the availability of board games over the network for visually impaired people.

The rest of this work is organized as follows. In Section II we discuss the need for tactile bi-directional feedback and in Section III we describe how this is introduced by our novel approach, detailing physical, control, and communication issues. In Section IV, we highlight the advantages in terms of hardware simplicity and monetary cost of our approach. Finally, we conclude in Section V.

II. Choice of Feedback Strategies

The sense of sight is the major perceptual channel for the human being. However, for visually impaired people this needs to be replaced with another sensory channel, such as touch or hearing. The tactile channel is more robust in noisy environments and it is also the only viable possibility for those blind people who are also deaf or have hearing impairments. We also remark that, more in general, haptic feedback is known to significantly improve human-computer interaction. Findings from several studies [7] show that visual feedback can be improved, and in certain cases even replaced, by tactile stimuli. At the same time, also audio feedback is known [8] to further improve the performance from haptic devices. For all these reasons, our proposed system can combine all three channels, i.e., simultaneously provide visual, audio, and tactile feedback in a multi-modal fashion.

In the following we will focus on the main original feature of our proposal, i.e., the introduction of a bi-directional tactile feedback. However, this solution is straightforward to integrate with audio feedback as well. We also point out that our system guarantees an improved usability for any kind of user, including sighted, blind, and even deafblind people.

Moreover, observe that our system does not only provide a vibrotactile feedback that stimulates the human subcutaneous tissue. Importantly, it also provides a concrete spatial feedback for visually impaired people. As players know, figuring out the spatial disposition of pieces over the board significantly improves the game experience.

Our strategy is original since common devices with tactile feedback use this feature simply to convey warnings or other binary notifications. Instead, we defined a bi-modal tactile interaction and designed a more expressive feedback environment based on several types of information. For the execution of continuous control operations, such as the task in which the user navigates over the screen, tactile feedback provides immediate spatial information to users, allowing them to modify their behavior according to their purpose: thanks to vibrotactile actuators, they constantly feel the trajectory of their movement and they are able to adjust it at any time. The challenge was to create the appropriate feedback also for discrete control operations (i.e. read a text or a symbol on the screen) without affecting or interfering with the information about continuous control.

A widely employed solution in this sense is to split information over two channels, i.e., to combine haptic continuous feedback with sounds associated to discrete events [8]. However, this solution would not be suitable for deafblind users and is more prone to errors when ambient acoustic noise is present. Our proposed solution implements instead a bi-modal tactile feedback through haptic channel splitting.

The rationale behind our idea is as follows. First of all, we observe that even blind people with hearing impairments are usually able to read Braille displays, thus we propose to use piezoelectric dynamic Braille cells [9]. This technology is used to mimic existing Braille chessboards [2], where tactile information allows recognizing checkers and pieces. Finally, we observe that there are different kinds of mechanoreceptors that respond to multiple levels of pressure [10]: rapidly adapting receptors react to an immediate stimulus, while slowly adapting receptors respond to continuously applied pressure. So, according to the type of operation (continuous or discrete control) the system provides different tactile feedback using vibrotactile actuators (continuous pressure) or a refreshing Braille tactile actuator (discrete stimulus). Also, this bi-modal tactile feedback allows the different actuators to be used in parallel (i.e. for the notification of an event, when the application alerts the user and requires him to read a text which is not in the cursor position) without any interference. As a consequence, we rely on the sense of touch as a common information source for several types of non-collapsing messages. For instance, with respect to the board game implementation, there are different types of information such as game status (the configuration of the board and the status of the game), time (elapsed and remaining), events and system responses that need to be adequately represented by messages delivered with an appropriate feedback strategy.

III. System design

The system architecture was designed to comply with a modular model, based on the concept of layers, especially conceived for interactive devices. It consists of three independent components, which are layered one above the other. The *physical layer*, which has the purpose of acquiring input and providing output, directly interacts with the user and passes information to the *control layer*. This is in turn the interface with data exchange over the network which happens through the *communication layer*. This last layer is connected to a computer and a network server and exchanges input and output data flow with the control layer. In our prototype, all the layers are assembled onto one board. The hardware enclosure of the system consists of a small plastic case that is driven by the user with one hand. The physical layer is placed over the surface of the package. The optical sensor is located underneath the device because it has to be in contact with the surface. Pairs of pager motors are located on both the left and the right sides; so, they are in contact with the distal and the in-

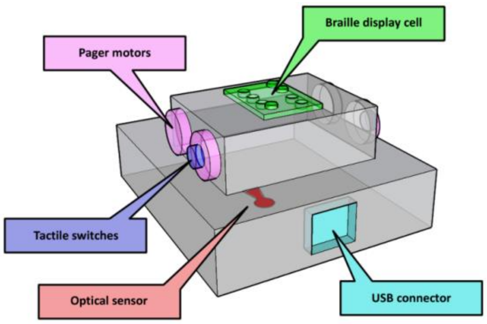

Fig. 1. Design of the hardware prototype

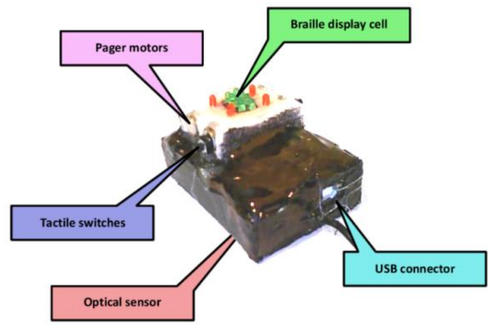

Fig. 2. First implementation of the prototype

termediate phalanges of the thumb and the middle finger of the user. The tactile switches are located above the pager motors in the distal area, one on the left and one on the right, so they can be easily pressed.

The Braille cell is placed on the top of the peripheral and it is in contact with the distal phalanx of the second finger. The control board is located in the device, on the same board as the communication layer. The peripheral can be physically connected to a computer via USB or serial port or it can have a wireless connection (Bluetooth or ZigBee). The inner structure of the communication layer may vary accordingly.

III.A Physical layer

The physical layer of the system was conceived as split into two separate peripherals embedded into one: the input and the output components. The input device consists of two main parts which rely on different sensors: the board navigator and the move selector. The output subsystem also consists of two components: one provides feedback about the navigation over the board and the other gives information about the content of squares. Fig. 1 describes the architecture of the physical layer and its modularity. This layer contains the circuitry connecting the electronic components (respectively sensors and actuators) that are required for input/output exchange.

The board navigator is an opto-mechanical component which is capable to detect two-dimensional motion relative to its underlying plane. It consists of an optical sensor whose purpose is to acquire continuous movements over a flat surface and to determine the distance between their starting and ending points within a certain time window. This can be implemented with a light-emitting diode (or an infrared laser diode) and photodiodes. The diode illuminates the surface; changes are acquired, processed and translated into movements on the two axes using ad hoc algorithms. Moreover, this kind of sensor is surface-independent. So, it is not required to have a dedicated chessboard, as recent computer mice do not need a special mouse-pad. The board navigator enables the control layer of the system to know the exact coordinates of the device, in terms of (x, y) pairs, with respect to a reference position. Then, a microcontroller translates the information provided by the board navigator into the movement of a pointer over the computer screen, as if it was a mouse cursor. We employed a common 3 mm red Light Emitting Diode (LED) and a standard complementary metal–oxide semiconductor (CMOS) sensor; so, the light bounces from the surface onto the CMOS, which acquires images to be processed with a Digital Signal Processor (DSP) algorithm. By doing so, it is possible to detect movement patterns, to evaluate the corresponding coordinates and to update the cursor position on the screen.

The move selector basically consists of two buttons, located in a position which is easy reachable by fingers (preferably the thumb and the middle finger) when the device is held. The purpose of the buttons is to issue commands (as sequences of button-click actions) that, in the case of chess, mainly regard moves. We employed low-profile (0.5 cm × 0.5 cm × 0.3 cm) tactile switches to acquire impulses. This kind of components provides excellent tactile feedback (sensitive release), high reliability (their mean actuation force is 1.35 ± 0.50 N) and a long life (from 200.000 to 1.000.000 expected cycles). Moreover, they are very cheap (about 0.20 dollars each). Also, extra buttons or features can be added to provide other control capabilities or more dimensions of input.

The provider of navigation feedback is realized with four pager motors, acting as transducers converting electrical signals into tactile stimuli to provide vibrations. These components are akin to those embedded into mobile phones and pagers to provide vibrations in addition to the ringing tone (or in replacement of it). Pager motors generate high amplitude of oscillating forces; also, they are compact, cost effective, highly customizable and suitable for small electronic appliances. Moreover, there are several packages, including the shaftless type. These units are a slight variant of the traditional vibrator motor design, since they are fully enclosed, with no external moving parts. The system device implementation consists of four pager motors whose operating voltage ranges from 2.5 to 3.8 V, having a maximum speed of 12000 rpm and a current absorption of 85 mA. We used miniaturized (1 x 1 x 0.3 cm) and light-weight (1g each) button-style (shaftless) motors, having a response time of 2 ms; however, there is a wide range of miniature vibrating devices which are available on the market and suitable for this project. The resulting implementation is shown in Fig. 2.

The architecture of the physical layer, as detailed in Fig. 3, contains several elements that deserve more emphasis. The provider of positional information consists of one light-weight and small-size Braille display cell. While the user navigates over the board, information about the value of each position is provided in real-time using a piezoelectric display unit which is capable of representing a refreshable Braille character. Piezoelectric cells have been developed for visually impaired people to allow them to read by touching a display with a line made of several cells. Each piezoelectric unit consists of six or

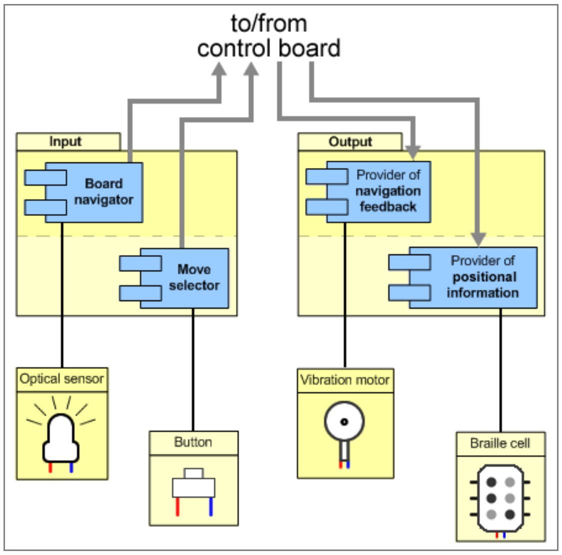

Fig. 3. Overview of the physical layer architecture

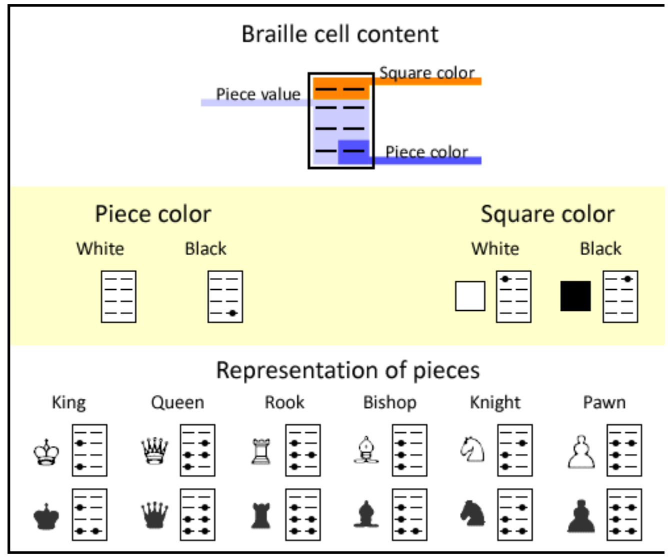

Fig. 4. Braille coding for chess playing.

eight actuators arranged in a rectangular array of 4×2 dots. The height of each point with respect to the cell surface is controlled by a bimorph which is stimulated with electrical signals to bend up or down. As a result, the actuators extend (rise) or contract (fall) and they create the Braille characters.

Several countries defined different standards for the horizontal and vertical distance between the dots, for the diameter of points, for the elevation of the piezoelectric actuator with respect to the surface of the cell and for other characteristics. We implemented an International Building Standard [11] compliant cell (2.5 mm for horizontal and vertical dot-to-dot distance, with a dot diameter of 1.5 - 1.6 mm and a dot height ranging from 0.6 to 0.9 mm). As well as this kind of components relies on direct-electrical control, it provides fast feedback to the user (usually Braille cells have a settling time which is about 0.15 seconds). Regarding the capabilities of the piezoelectric Braille cells in terms of information representation, as well as each cell consists of 8 dots, it is possible to encode up to 256 symbols, which is a number sufficiently high for any kind of board (and even card) game.

III.B Control layer

This layer consists of the processing unit (microprocessor) that manages the device operation. Its purpose is to translate physical stimuli into logical messages for the game. When the user navigates over the board or selects a starting and an ending positions, the microcontroller receives sequences of electrical inputs from the sensors located in the physical layer, converts them into logical messages and sends them to the communication layer; conversely, when data are received from the upper layer, the control layer converts them into stimuli and triggers the actuators, e.g., by firing the pager motors or displaying a symbol on the Braille cell. We implemented both control and communication layers using an open source multi-platform hardware tool for rapid prototype development equipped with USB connection, the Arduino Diecimila control board [12]. This includes a 16 MHz ATmega168 microcontroller, 14 digital input/output pins and 6 analog inputs. Also, it supports Pulse Wave Modulation (PWM) on 6 output pins. The firmware is programmed within the Processing environment in a C-like or Java-like language.

The board navigator acquires input about the spatial location of the device (if it is not in sleep state) at a high frequency (1000 Hz). The microcontroller processes the sampled CMOS signals and converts them into pairs of bytes representing the actual coordinates. Then, it sends them to the communication layer by raising a pos(x, y) event with a frequency equal to the sampling rate. Also, each button-click raises a different event that is sent to the device driver through the communication layer. Sequences of clicks generate command configurations, which are interpreted by the device driver. For instance, the user selects the starting position of a move by clicking once button A (start-square selection button) and then he drops the piece on the final position by clicking once button B (end-square selection button) or clicks button A again to choose another (non-empty) starting position. By clicking both the buttons at the same time, the board navigator is reset to the default position (center of the chessboard).

The microcontroller in the control layer receives and executes commands from the transport layer through serial communication. Each incoming message consists of 2 bytes: the first one contains the command and the other one contains the parameter. Thus, up to 255 commands can be implemented. For example, we can trigger the provider of navigation feedback, the provider of positional information, or to generate arbitrary time delays. The provider of navigation feedback is triggered by vibrating one or more motors with a given intensity. This is done by a digitally-generated analogue PWM output: voltage amplitudes are represented by integers with four possible levels (zero, low, medium, high). As we have 4 motors, this information can be encoded with a byte (2 bits per each motor).

A positional information command changes instead the Braille cell configuration by raising or lowering one or more piezoelectric actuators. Its parameter represents the state of each of the dots (0 for low, 1 for high) starting from the first row and the first column. This can be used to display for example one of the 256 possible values of the pieces. Fig. 4 reports an example for chess, using the international code of Braille chess.

III.C Communication layer

This module consists of the electronic components that allow the device to transfer data and to interact with the network. The system is designed to support several types of wired or wireless connections. The control system natively implements a standard serial RS-232 port. Also, we added Universal Serial Bus (USB) support, which also provides power supply within the connection cable. Several wireless solutions, such as Bluetooth and ZigBee can be used with an additional battery.

Due to our modular approach, the network interface does not require any special change to the device. This is true also for the possibility of playing different games with the same device, which happens thanks to a client/server model implemented in the local communication protocol.

The game software of the system acts as a client requesting service to the device driver of the hardware where the application is run. We enabled their processes to establish a local User Datagram Protocol (UDP) connection and exchange streams of data and share messages between the client (the game software) and the server (the device driver). In this way, a single peripheral is capable of interacting simultaneously with several software applications.

Although the client/server model introduces an higher-level abstraction, a serial communication is realized between the driver and the peripheral; it occurs without any handshaking procedure and it has the following settings: the baud rate of the transmission is set to 9600, the number of data bits encoding a character is set to 8, there is no parity bit and one stop bit is used.

IV. Feasibility considerations

In this paper we mostly focused on the conceptualization of hardware features; thus, we designed the peripheral to achieve high modularity and component independency. We preferred to have a rapid device development and we used a commercially available hardware package. In this section, we discuss implementation issues which show the advantage of our proposal with respect to existing solutions.

The most expensive part of our device is the piezoelectric Braille cell, which can be found as a stand-alone device with cost of about $35. Other components are relatively cheaper and easy to found on the market. The overall cost for a complete device can be estimated below $80 for a unique prototype. Our approach is cost-effective with other possible solutions, e.g., a chessboard made of a unique Braille display, with a factor of 1/64. Plus, it offers also the advantage of being portable for non-standard checkers (e.g., shogi which is played on a 9×9 chessboard). Moreover, we observe that all the sensors and the actuators (except for the Braille cell) can be gathered from spare hardware and non-functioning peripherals (i.e. a computer mouse and mobile phones). The implemented prototype was built using this rationale, so the only expense is that of the Braille cell, whose cost is of the same order of magnitude of a mechanic chessboard with neither electronic nor network support.

Further improvements might concern the implementations of power saving techniques to reduce energy consumption, especially for the battery-powered wireless model. Similarly to a computer mouse, our device can include a standby-mode during which the laser or the LED is blinking instead of continuously active. Moreover, since board games are turn based, several power saving conditions can be introduced in order to save energy, for example sleeping states during the opponent's move. This function would also increase the life of the laser (or the LED).

V. Conclusions

We developed a practical and low-cost system architecture which enables remote board game playing over a network for visually impaired people. Our solution is cost attractive and easy to implement. Moreover, it can be combined with other feedback techniques and is simple to use even for non-impaired people. We also discussed several feasibility issues showing that the practical implementation of the proposed solution is easy and cheap.

Further experiments are currently under study to test our device in a real game situation. In this way, we will be able to identify the response of blind players and gather detailed information about the benefits of the proposed tool.

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