A distributed architecture for facilitating the integration of blind musicians in symphonic orchestras

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1. Introduction

The technological evolution in the last decades (Internet, WWW, e-Commerce, wireless networks, etc.) has led to a new computing paradigm: “computing as interaction”. In this new paradigm, computing is something that happens by and through the communication between computing entities. This approach, based on the notion of computing as an inherently social rather than isolated activity, is leading the way to new forms of conceiving, designing, developing and managing computer systems. An example of the influence of this view is the emerging model of ambient intelligence (AmI) and distributed computing. The term ambient intelligence (AmI) emerged in 1999 from a proposal put forth by the Information Society Technology Program Advisory Group (ISTAG) of the European Community (ISTAG, 2003), based on the concepts of ubiquitous computing, which is applicable in such areas as artificial intelligence, home automation, intelligent agents, etc. (Aarts, 2004; Friedewald, 2003). Ubiquitous computing and AmI influence the design of protocols, communications, systems integration, devices, etc. (Lyytinen & Yoo, 2002). Ambient intelligence is described as a model of interaction (Tse & Viswanath, 2005) in which people are surrounded by intelligent devices, aware of their own presence, context sensitive and able to adapt to the user’s needs (Friedewald & Da Costa, 2003) through embedded technology. These non-invasive devices are transparent to users (Anastasopoulos, Niebuhr, Bartelt, Koch, & Rausch, 2005; ISTAG, 2003) and facilitate their daily activities (Corchado, Bajo, & Abraham, 2008; Emiliani & Stephanidis, 2005).

A clear example of an application of this technology can be found in the field of disabled people, particularly the visually impaired. There are many situations that require ambient intelligence solutions in this specific area. This paper presents a system that facilitates the integration of the blind people into several everyday activities. DIAMI architecture provides a mechanism for conveying information to blind people in real time, in a ubiquitous way, using a motion capture system based on WiiMote technology (Cheng, Freeman-Aloiau, Guo, & Pullen, 2007) and a system for transmitting information through a series of vibrations. DIAMI architecture was initially applied to the problem of integrating blind musicians into orchestras, but can be easily adapted to work in other environments. DIAMI allows a conductor to transmit instructions to the blind musician through an infrared LED located on the tip of the baton. The WiiMote system captures the movements of the conductor, which are interpreted in a central computer and sent to the visually impaired musician via vibrations. The blind musician perceives the vibrations through a bracelet.

The aim of the work presented within this paper is to obtain an innovative solution to facilitate the creation of dynamic interactions with visually disabled individuals in scenarios such as symphonic orchestras, educational environments, etc. DIAMI is a dynamic architecture whose goals focus on:

- Providing a wireless interaction system that can capture movements (for example, those executed by an orchestra conductor) and to transmit these movements to a visually impaired musician in real time.
- Designing a method for motion capture and encoding.

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• Designing a method for signal reception and decoding that can transform the signals to a format capable of being understood by a blind person.
• Defining a case study consisting of a symphonic orchestra with blind players, in order to evaluate the system and methods proposed.

The remainder of the paper is structured as follows: Section 2 presents the problem that motivates most of this research. Section 3 describes the principal existing alternatives for motion capturing and transmitting vibration signals. Section 4 presents the DIAMI architecture proposed in this paper to facilitate the integration of blind musicians in orchestras. Finally, Section 5 shows the preliminary results obtained and the conclusions extracted from these initial results.

2. Problem description

The development of ambient intelligence is essential for automatically analyzing data from distributed sensors (Loomis, Golledge, & Klatzky, 1998). One of the main objectives of ambient intelligence is to achieve solutions in the fields of medicine and disability. There is still much work to do, including the development of systems and technology that focus on improving services, particularly for the visually impaired (ISTAG, 2003). Over the last decade, the Internet has revolutionized the world of communications and distributed computing. This revolution has given people greater access to information and allowed them to address new challenges. After the initial development of the Internet, wireless communication networks such as GPRS and UMTS (Tse & Viswanath, 2005), and the development of mobile devices like phones and PDAs, have provided novel opportunities. This technology can help build distributed systems more efficiently and offers facilities to face new problems (Corchado, Bajo, de Paz, & Tapia, 2008; Corchado, Bajo, et al., 2008). Wireless networks are ideal for networks like the Internet, and for facilitating access to real time and distributed information. With regards to interaction systems based on data transmission, there are still many problems to resolve, most of which stem from the technology used in their development. However, even with these limitations, the potential of ambient intelligence systems is indefinite.

Ambient intelligence (Bajo et al., 2009; Friedewal, 2003) provides intelligent environments with a high technological content in which technology is adapted to the needs of the users. One of the major concerns of ambient intelligence is to achieve environments that facilitate the daily lives of disabled people (Corchado, Glez-Bedia, de Paz, Bajo, & de Paz, 2008; Corchado, Bajo, et al., 2008). Within this goal, we may find the need to develop new interactive systems that enable people with visual disabilities to carry out everyday tasks. A clear example of this type of work involves the participation of blind musicians in orchestras, as shown in Fig. 1. Musicians with visual problems have to be somehow integrated within an orchestra because they are incapable of following a score or the instructions of the orchestra conductor on their own. Currently, blind people are forced to memorize entire scores, which involve a considerable effort on their part (Banda de Música para ciegos, xxxx). In addition, they can experience serious problems in responding to incidents or changes in the normal thread of the score, or synchronizing with the other musicians of the orchestra. This simple example illustrates the interaction problem that will serve as the initial case study for the development of this project. It provides a specific problem with a solution that can be easily extended to other areas requiring the integration of blind persons in our society.

There are currently a significant number of professional blind musicians, and several orchestras even include blind members; a feat that is obtained not without difficulty. For example, the Symphonic Band for the Blind (Banda de Música para ciegos, xxxx) uses a system whereby through soft baton blows of the conductor, the musicians perform in a precise manner. In this symphony, the musicians are required to memorize the scores. What is still missing, however, is an interaction system that enables blind musicians to integrate within symphony orchestras comprised of sighted musicians. At present there is no known system of this kind that allows a blind musician to receive instructions from the orchestra conductor in a simple, ubiquitous and non-invasive way. Such a system requires a mechanism that allows the conductor to send signals to blind musicians, and a receiver that allows musicians to receive and interpret the instructions in real time.

The main role of a conductor is to coordinate the members of the orchestra, and to interpret the musical structure, adjusting certain flexible elements of a musical score. Basically the conductors communicate with the musicians by using a very specific and developed language of gestures. The most basic structures consist of beat-patterns that, when embellished through scaling, placement, and trajectory, conveys the flexible elements interpreted by the conductor. A musical score is divided into a finite number of bars or measures. Every measure is identified by a line perpendicular to the staff called a barline. Each bar contains a number of musical figures. The type of bar is based on the notes it contains. We will focus on the three most common types of bars, which can be seen in Table 1.

The conductor performs hand and arm movements to give instructions for each beat. These movements can be distinguished by their importance:

- **Tempo**: The tempo indicates the speed that is most adequate for the bars. Thus the conductor, with a periodic movement of the right hand, indicates the tempo to be followed. The count for each bar begins with the hand in the higher position. There are different types of movements, depending on the time signature used, as shown in Table 2.
- **Entrance**: The conductor indicates the entrances for both individual players and instrumental sections during the representation. The conductor uses the left hand to indicate the entrance.

![Blind Musician](image)

**Fig. 1.** Blind musician and orchestra conductor.

<table>
<thead>
<tr>
<th>Type of bar</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>2:4</td>
<td>Contains two units of time</td>
</tr>
<tr>
<td>3:4</td>
<td>Contains three units of time</td>
</tr>
<tr>
<td>4:4</td>
<td>Contains four units of time</td>
</tr>
</tbody>
</table>
used on portable hard drives to detect sudden drops, whereby the head of the device is immediately locked, or with the activation of the airbag systems for automobiles. The accelerometers are chips that measure both the acceleration and the direction of movement by checking changes in their internal electrons. In this way, it is possible to obtain relative movements in all axes of coordinates, data acceleration, and to detect spins, movements in the air, leaning, etc.

With regards to gyroscopes, most MEMS gyroscopes are based on the Coriolis Effect (Albarbar et al., 2009). The Coriolis Effect is an apparent deflection of moving objects when they are viewed from a rotating reference frame. The increase in speed produces a decreased acceleration and deceleration. An electronic gyroscope contains two distinct parts: a polysilicate resonant element, which actually makes an outward or inward vibrating movement with respect to the gyroscope’s axis of rotation, and another part that is fixed and perpendicular to the vibration of the first movement. Together, the two form a capacitive structure capable of containing an electric charge. When the gyroscope is not spinning, the distance between the two elements is maintained and the capacitance of this structure remains unchanged. However, when the gyroscope turns, the following effect takes place: the resonant element moves along the rotation axis as a result of the vibration, and experiences an acceleration or deceleration, which is produced by the Coriolis Effect. These accelerations/decelerations are translated into forces that pull in opposite directions, thus affecting the resonant mass. These forces push the body either closer to or away from the fixed element, changing the capacity of the capacitive structure in proportion to the speed of rotation. These capacity changes are detected by sensing elements, which are able to determine the rotational speed of the gyroscope and express it as a voltage output.

The WiiMote system (Cheng, 2007) includes MEMS devices, which send the data from motion detection directly to a Bluetooth chip from Broadcom Technologies integrated into the control board. This chip is responsible for instantly sending data to the Wii system for reception in another Broadcom chip and further processing and display/screen interaction. Communication in both directions uses the 2.4 GHz band and provides data on flows of 2.1 M bits/s, enough to handle all devices at once in real time. Broadcom has included special enhancements that allow very low latency between console and command. In addition, the Bluetooth component of the company has low consumption. This system allows devices to wirelessly connect via Bluetooth (Muller, 2000) and Wi-Fi (802.11 b/g) (Tse & Viswanath, 2005). A priori, as the two technologies work in the 2.4 GHz band, there would be some interference generated. To fix this problem, Broadcom has its own optimized wireless performance for optimal simultaneous output rate, minimizing the possibility of collision of radio signals, obstructions or other interference.

There are different possible uses for a vibrating receiver system, including smart clothing or devices that incorporate small vibrating motors (Narayanaswami & Raghunath, 2002). Given the specific characteristics of the problem faced in this study, the use of Bluetooth bracelets that emit vibrations was deemed the most appropriate. The possibility of using wireless Bluetooth technology provides a real-time transmission of the signals received from the WiiMote system, and a simple and ubiquitous vibrating system to transmit instructions.

Fig. 2 shows a vibrator and a Bluetooth vibrating bracelet. Fig. 2(a) presents a vibrating motor. The motor carries an eccentric wheel, which has a considerable mass relative to the motor. When the motor is fed with its operating voltage, the motor rotates at high speed and, due to the eccentric mass of the flywheel, produces an oscillation of this frequency. The vibration of the motor produces a clear instruction to the person wearing any device built
with the motor. Its weight (less than 2 g), its small size and low power consumption, make it ideal for all kinds of applications. It can be also considered a silent alert system that allows alert signals to be sent to people with hearing and visual disabilities, and generally all other applications that require silence.

Fig. 2(b) shows a vibrating bracelet that vibrates when the phone rings, located at a distance up to 5 m. It is the LM957 device developed by LM Technologies.

The next section presents the proposed DIAMI architecture for facilitating the integration of blind musicians into orchestras, and describes its components in detail.

4. DIAMI: ambient intelligent-based architecture for blind musicians

This paper proposes an ambient intelligence-based system (IS-TAG, 2003) that uses a transparent and ubiquitous communication system to enable a blind musician to receive instructions from an orchestra conductor in real time. In this way, through the use of a transmitter installed on the baton of a conductor, a minimally invasive system receiver worn by the musician, and a coding system that allows the transformation of movements into vibrating instructions, a blind musician can receive orders from the conductor in real time and be synchronized with the other members of the orchestra.

After interviewing various blind musicians and orchestra conductors, different conclusions were obtained. First of all, it is necessary to develop a new code that allows the signals corresponding to each of the movements to be associated with electrical signals that are transformed into vibrations. The task was complicated, but solvable after taking into account certain common patterns of behaviour. In particular, the signals for each of the conductor’s movements (up, down, and the intensity-crescendos–decrescendos) must be clear and distinguishable from each other. In principle, the tempo that the conductor provides may have minor difficulties for coding, as with the signals indicating intensity, but it is more difficult to encode the intermediate points. This type of problem can be solved by using accelerometers or dynamometers. In our case we consider it appropriate to use the WiiMote system (Cheng, 2007). Among the options considered for the receiver were armbands and headphones. Ultimately a bracelet-type device was selected since it could be placed in the chest or back area, depending on the instrument that the musician plays, both of which are areas where the vibrations would not affect the normal activity of the musician. The conductor’s instructions are carried out in real time using continuous vibrations to transmit signals, which are more precise and less distracting for the musician.

Fig. 3 illustrates how the DIAMI system provides a mechanism for wireless interaction between the conductor and the blind musician. The DIAMI system has a series of components, which are described below:

- **Motion sensor**: with the use of a baton, the conductor transmits instructions to the blind musicians. In an attempt to facilitate interaction with the blind musician, DIAMI proposed the placement of an infrared sensor at the tip of the baton, which is powered by a button-type battery located at the base of the baton.
- **Motion capture**: the motion capture system is based on the WiiMote system, which can detect the trajectories drawn by the infrared sensor placed on the tip of the baton handled by the conductor.
- **Motion interpretation and encoding**: the movements captured by the WiiMote system are sent to a processing system, installed on a central computer, where the movements are interpreted and codified in the form of vibrations. The encoded information is sent to a bracelet placed on the arm of the blind musician, using Bluetooth communications technology.

Fig. 3. DIAMI architecture. The DIAMI architecture contains a series of components: motion sensor, motion capture, motion interpretation and encoding and vibration system.
– **Vibration system**: the blind musician’s bracelet receives information that contains the instructions from the conductor, which are turned into vibrations. The musician interprets the information and is able to follow the conductor’s instructions. The bracelet contains 4 vibrators, as shown in Fig. 2.

Fig. 4 shows the placement of the vibrators on the arm of the blind musician. Vibrators were distributed in a strategic way to avoid the possibility of confusion regarding the interpretation of the vibration. The coding of the movement takes into account any changes in tempo and intensity. The system analyzes the baton movements made by the orchestra conductor, and focuses on the detection of changes in the direction of the movements made by the baton to inform the blind musician. Different movements were taken into account in order to detect special situations, such as the beginning of a new score, the lateral displacement of the conductor, or possible variations in the pulse of the director. The next section presents the preliminary results and discusses the conclusions obtained.

### 4.1. Motion capture

The mechanism used for motion capture is based on the Nintendo WiiMote system (Cheng, 2007), but not in the traditional way. In the Nintendo system, infrared LEDs describe a rectangle on the screen, so it is possible to know its relative position through a combination of triangulation using the IRLeds (movement in the plane) along with accelerometers and gyroscopes. The movement of the baton of a conductor with an IRLed on top can be interpreted as a movement in the plane with horizontal and vertical coordinates. An infrared sensor will describe movements over the detection rectangle, and these movements will be detected by the WiiMote system installed in the remote, as shown in Fig. 5.

It is possible to establish the remote as a fixed sensor, which enables a virtual plane to detect the movements of a baton in which an IRLed has been mounted. Furthermore, it does not emit visible light, and should not burden the players of the orchestra or audience. The plane is linked to the conductor, as shown in Fig. 6.

### 4.2. Software interpretation of the captures movements

The captured data are interpreted and codified using the GlovePie software (GlovePie, 2009), then transformed into vibrations. Because our vibrators support up to eight different intensities of vibration, we have designed a map that matches the rectangle where the system collects the WiiMote movements. The map is divided into seventeen zones per axe, leaving a neutral zone in the center, as shown in Table 3.

Movements up, down, left and right are coded in such a way as to correspond to each of the top, bottom, left and right vibrators. If the movement performed by the orchestra conductor is diagonal, then it is associated with two vibrators. For example, if the baton describes a diagonal upward and to the right, the right and superior vibrators will be activate. In addition, depending on the location of the movement, the motors vibrate with different

Fig. 4. Signals as received by the musician: the movements executed by the orchestra conductor are encoded and transformed into vibrations. DIAMI considers the changes of direction in the conductor’s baton as the key to transmitting the instructions.

Fig. 5. Typical range for detecting infrared light from the WiiMote system. The distance and amplitude depend on the lighting conditions.

Fig. 6. The conductor remains within the range of motion capture, so that the movements of the baton can be captured.
intensities. If the movement is located in high zones, the vibrator vibrates with superior strength, allowing the musician to follow and identify the movement. The neutral zone is used as a reference point. If all the vibrators are inactive, then the director’s baton is in the center of the plane, as shown in Fig. 7. This also serves to identify a transition from one movement to another direction.

4.3. Transmission of the captured movements to the vibration system

Since the vibrators in our first prototype were connected to a parallel port and GlovePIE does not work with a standard parallel port, we were initially able to recognize and interpret the movements, but had no way of connecting directly to the output of the parallel port. To solve this problem, we developed an intermediate layer of software in which a motion drawn within the rectangle of detection was automatically assigned a zone (each axis) that was identified as a keyboard pulse. This way, if movement was detected within a particular zone, the corresponding keyboard signal was activated and the pulse could be captured by a second application capable of sending information via the parallel port. An example is shown in Fig. 8.

In a second prototype we used an Arduino Bluetooth chip (Arduino Bluetooth chip, 2009), capable of emulating a parallel port and directly transmitting the signals to the vibrators. Regarding the control of the vibrators, the sender encodes the positions of the baton and sends this position to the receiver (Pos1, Pos2, Pos3, and Pos4). The receiver uses its Arduino Bluetooth chip to activate the vibrators and to vary the increasing or decreasing of the life cycle of the motors. Fig. 4 shows the placement of the vibrators on the arm of the blind musician. Vibrators were distributed in a strategic way to avoid the possibility of confusion in the interpretation of the vibration. Different movements were taken into account in order to detect special situations, such as the beginning of a new score, the lateral displacement of the conductor, or possible variations in the pulse of the director.

In order to obtain Bluetooth communication with the bracelet worn by the blind musician, an Arduino chip (Arduino Bluetooth chip, 2009) is used, which incorporates a number of analog and digital inputs, in addition to the outputs connected to the vibrators, as shown in Fig. 9. A wired connection is required, the musician is free to wear the bracelet elsewhere. The Arduino chip has a programmable memory in a reduced version of C language, which resolves any problem with the parallel port.

5. Results and discussion

Wireless technology is particularly promising as a support to the new paradigm of computation as interaction. Sensors and communication devices facilitate sending and receiving information in a ubiquitous manner. The DIAMI system proposed in this paper presents an innovative technological solution to efficiently and dynamically facilitate the reception and processing of instructions in real time for visually impaired individuals in areas such as orchestral music or education.

The DIAMI system has allowed us to develop an interactive system that is able to capture movements (such as those produced by the baton of a conductor) using the highly popular WiiMote system (Cheng, 2007), and transforming the movements into wireless signals that can be sent to blind people, who can interpret the signals in real time. Moreover we have obtained an initial prototype that supports the implementation of systems based on the DIAMI architecture in real environments. In addition, DIAMI provides a method to facilitate the capture and encoding of signals from movements, as well as a method for receiving signals that can be decoded and formatted in such a way as to be easily understood by a blind person.

To validate the system, we designed a series of tests. The case study, which involved 5 blind musicians and 2 conductors, allowed us to evaluate the system and, more concretely, the improvement of the knowledge acquired by the blind players. Specifically, we developed 5 scores presented one at a time to each blind musician by a conductor. Five tests were conducted for each of the individuals. Each of the tests had a maximum duration of 10 min. Fig. 10 shows the results of 5 tests performed in the case study with blind musicians and the evolution of the success of each blind musician in the tests. As shown, the success rate was lower in the early tests, and increased as new tests were performed. The horizontal axis represents the time (the tests), and the vertical axis the number of successes over time. It is usual to find errors at the beginning of a new task. In the later stages the error rate decreased, but the subjects had also learned and reached a plateau. The task of learning for the DIAMI system presented in the case study is steep at the beginning and then increasingly flat. This means that great process improvements were made during the first tests, and the learning curve flattened off as the musicians reached some level of mastery.
was made at the beginning, but after a while acquiring new knowledge became more difficult.

Fig. 11 shows the subjects’ satisfaction level over time, which increased substantially, especially after the third test. At the beginning, the system obtained a low evaluation, basically due to the fact that the system was new and had some problems; but as suggestions were incorporated, the vibrating signals approximated the musician’s needs. User satisfaction is measured by personal opinions and indirect observation on the auditory results. The user opinions are obtained from a questionnaire that the musician completes after every test.

The degree of acceptance by the users involved in our system is very high, as shown in Fig. 12. Fig. 12 shows a 100% acceptance by sighted musicians, because the system does not in any way affect the development of their own functions. The acceptance of the blind players was 98%, despite the initial learning difficulties, although there are some suggestions for using vibrators in parts of the body other than the arm. Finally, the acceptance by the conductors was 87%. Conductors who tried the system presented a certain rejection to the inclusion of hardware elements in the baton, as well as to the training period necessary for the system.

Fig. 13 shows the percentage of error that occurred during the tests. The initial tests showed an error rate above 20% in the interpretation of the score. This percentage was primarily due to errors committed by the blind musician and the conductor in the use of the system. After the third test, the error rate was reduced to 8%. From that point on the error rate remained at 2%. This error could be reduced with a higher level of training in the use of the system.

Table 4 presents a comparison of the characteristics for different interaction systems for visually impaired people. The DIAMI architecture is compared to sound (Loomis et al., 1998) and tactile (Gallagher & Frasch, 1998) interaction systems. As shown in Table 4, the DIAMI presents certain advantages, since it provides motion...
in terms of ambient intelligence (Corchado, Glez-Bedia, et al., 2008; Friedewald, 2003), and provides improvements in the field of disabled and dependant people.

Although the initial results are promising, still much work required. It is necessary to define a test scenario based on a real musical orchestra, which would take into account the unique profiles for each blind musician, thus allowing us to perfect the mechanisms that allow interaction between the users involved in this scenario. Moreover, it is necessary to consider different communication problems and errors that could arise in real scenarios. It is also necessary to develop and implement the policies necessary to interact with blind musicians in general, not just those who perform in orchestras.

Our future work focuses on testing the system in real environments, looking for feedback to adjust and improve the proposed solution, bearing in mind new benefits for the blind. At the same time, we aim to analyze the viability of applying the DIAMI system to other scenarios, such as obstacle detection, or interacting with blind users in shopping centers or educational environments. That is our next challenge.

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References