ACCELEROMETER-BASED COMPUTER MOUSE FOR PEOPLE WITH SPECIAL NEEDS

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Abstract: A great deal of human-machine interaction depends on hands, and so does access to information technology services. People unable to use hands do require special devices that replace computer mice or touchscreens. In this paper we present a building kit for a full-featured computer mouse that is controlled by head movements. The resulting kit includes an easy-to-find bill of materials, instructions to build the device and to use it. The experiments conducted with already built devices showed that it works pretty well for most people after a short period of adaptation.

Keywords: DIY (Do It Yourself) accessibility device, HCI (Human Computer Interface), interfaces and techniques for information access, user adaptability.

Introduction

Computer mice and other interface devices rely mostly on hand movements thus becoming useless to those with impaired hands (section on target users).

Fortunately, there are several interface gadgets that partially or totally cover the functionality of traditional computer mice through the use of

elements that can be operated by body parts other than hands (section on mice and mouse-like devices).

Unfortunately, they are expensive, require software installations, lack of some of the functions of a regular computer mouse, and, besides, are difficult to adapt to a wide range of users.

On one hand, these mouse-replacing devices are rare and expensive because of the inexistence of a big market able to generate enough return. On the other hand, we all have the possibility of building devices adapted to our needs thanks to the large-scale market of everything related to the information and communication technologies and, specifically, of DIY electronic components.

In a similar way than proposed by Hurst and Tobias (2011), ATSolutions (atsolutions.org) or DIYAbility (www.diyability.org), in this work we have taken advantage of the availability of DIY components to build an open-source, hands-free computer mouse at an affordable prize. Hence, potential users can have easy access to an earphone-mounted mouse that can be adapted, i.e. programmed, to best suit their needs.

Most of the already existent mouse-replacing devices sense head movements instead of hand and finger ones to determine pointer displacements and mouse actions. To do so, an accelerometer can be placed onto an earphone and data from it read and processed on an electronics board such as Arduino, BeagleBone or Raspberry Pi, to mention a few. At its turn, the electronics board emulates a conventional USB computer mouse so that no special drivers or software has to be installed (see Fig. 1.)

The result earphone-mounted computer mouse can significantly improve the life quality of those who cannot use their arms and hands, temporarily or permanently, providing an alternative to accessibility to computers and similar devices.

Therefore, the main goal of this work is to make available all the necessary elements to build a "computer mouse earphone" to anyone, and so, make it available to any other person in need of it, without any other requirements.

Figure 1. Earphone-mounted mouse emulator. Source: authors.
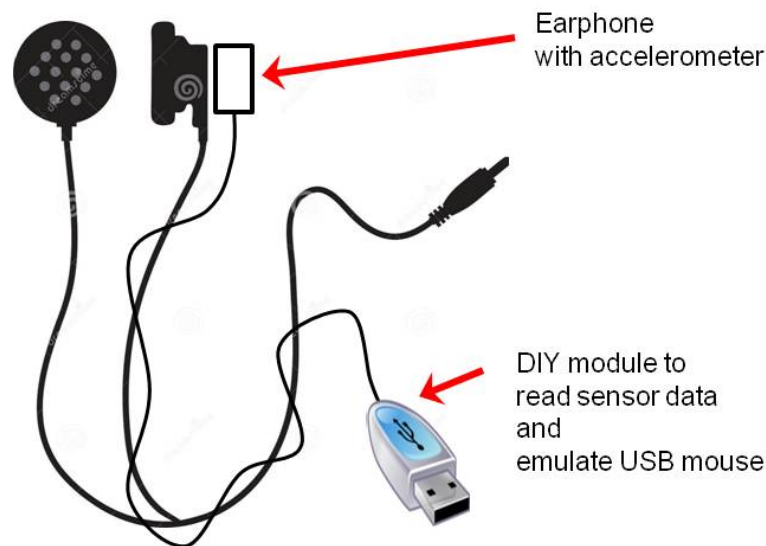
The proposed device (section on the accelerometer-based computer mouse) is inexpensive, with components commercially available and easy to buy. Its assembly is straightforward, with no need to have any technical knowledge or specific tools, and the software is downloadable for free on the Internet. It does not need any further software installation on any computer or portable device it is used with.

In this paper, a second version of the device is presented, that takes into account the first users' opinions of the original one. The changes in the embedded software for the improved version consisted, basically, of replacing the original "head position mirroring cursor" (Ribas-Xirgo & López-Varquiel, 2015) by a "head pushing cursor" (subsection on principles of operation). The idea of the last one is that the user moves the cursor on the screen by virtually pushing it with the head. For example, if he or she moves the head upward, then the pointer moves to the top of the screen.

The resulting device is easy to use so that the user does not need any particular, long training (subsection on user's guide).

Some devices were built to be able to test them with real users to determine its user-friendliness and to be able to adjust both the head movement tracking and the identification of gestures of the users to their intentions (concluding section.)

Target users

Anyone that may take advantage of using a head-tracking mouse instead of a conventional one can use it. However, the focus of such kind of devices is on people with special needs willing to access to computing devices and applications like people without disabilities. Unfortunately, diversity of impairments makes it difficult to know the number of potential users.

According to the Instituto Nacional de Estadística (Spanish National Statistics Institute), almost four million people (out of 47 million Spaniards) have some disability type and almost a 40% of these have problems with bones and articulations (Instituto Nacional de Estadística, 2008). Many of these people are potential users of the proposed device.

A more specific segment of population that might be candidate users consists of those people having paraplegias, which account for fifty thousand people in Spain (Jara, 2011). By extrapolating Mexican statistics from a Bahena-Salgado and Bernal-Márquez (2007) work, approximately half of them have tetraplegias and are possible users of this kind of devices.

However, it is worth noting again that the diversity of people's conditions makes it difficult for a single product to suit all specific needs and only a fraction of them might be really taking profit of the proposed device. In fact, is designed for people with good control on head movements, i.e. able to keep it still, but slight tremors should not greatly affect its functioning. Among them, anyone willing to use common software on any device may find this gadget useful. Take into account that, apart from computers, mice can be connected to mobile devices with Android (Hoffman, 2013), iOS (Karns, 2011) and, even, Microsoft Windows Phone (Schenck, 2014).

Furthermore, as people is getting used to interfaces other than mice, keyboards and touchscreens, a head movement tracking mouse can be used by any person that might find it interesting to. In fact, the use of, for example, Wiis from Nintendo or Kinects from Microsoft, have familiarized people with new ways of interaction with computers. And this contributes to see hands-free mice as a complementary form of man-machine interaction.

To sum it all up, the target users of the proposed device are some of those people that cannot access computer applications because of a temporal or permanent disability to use hands and fingers to manipulate a pointing and selection device such as mice or touchscreens, and some of those that might look for a different user experience with computers.

It is also important to highlight that, by using the proposed full-featured mouse and virtual keyboards, any user can have access to regular computer applications without further ado. Therefore, users are able to establish and maintain social relations through Facebook, Twitter, or any other social network system, can play games and work with computer applications, regardless of their possible disabilities.

Mice and mouse-like devices

The idea of substituting mice by more "natural" alternatives for pointing and clicking is not new. For example, back in 2006, Microsoft had foreseen a special glove (Ranta & Bathiche, 2006) to replace mice and, more recently, Leap Motion offers a device to be used like a touchpad (Panneta, 2013). In fact, touchpads and touchscreens have made mice obsolete to most people. However, these "mouse substitutes" still rely on hands and fingers.

Fortunately, there are more and more machines that have frontal cameras, and they can execute programs that transform users' gestures in front of the camera into mouse movements and actions (Graveleau, Mirenkov & Nikishkov, 2005; Palleja, Rubion, Teixidó, Tresánchez, Fernández del Viso, Rebate & Palacín, 2014; Pereira, Neto, Reynaldo, Luzo & Oliveira, 2009). Free cam-based virtual mice include EyeMouse (Mónaco & Ponieman, 2008), HeadMouse (Teixidó, Palleja, Tresánchez, Font, Moreno, Fernández del Viso, Rebate & Palacín, 2013) and Enable Viacam (Mauri Loba, 2008). However, they do not implement all the features of conventional computer mice. EyeCan (Kee, 2012) also uses computer cameras, but requires extra components.

With the success of the video game consoles like the Wii of Nintendo and with the commoditization of accelerometers, there are also solutions that incorporate them to build computer mice or devices alike. Many of them are commercial and protected by patents (Tong, 2000; Breen & Gerasimov, 2008; Ishimatsu, Irie & Takami, 1997; Schmid, Baettig & Schmid, 2003; Rodgers, Higgins, Gagnon & Farr, 2010). However, commercial or not, these solutions require user adaptation and, besides, have accuracy (LoPresti, 2001) and fatigue (Bureau, Azkoitia, Ezmendi, Manterola, Zabaleta, Pérez & Medina, 2007) problems.

Anyway, special needs people do require hands-free mice and there are commercial products that offer a similar functionality (see table 1 for a short list of them.) Unfortunately, they are pricey and limited to some platforms. Another important drawback of previous mouse replacement options is that they need installing software, which limits the number and type of computers and other devices they can be used with.

Table 1. Pointer devices.

Device	Sensor	Body part	Price
Computer mouse	Optical, others	Hand	< 100€
FootMouse (Hunter Digital)	Electromechanical	Feet	250€
SmartNav (Natural Point)	IR camera	Head	400€
LaZee Mouse (LaZee Tek)	Accelerometer	Head	500€
QuadMouse (Quadadapt)	Electromechanical	Lips, tongue, chin	550€
IntegraMouse (Adapt-it)	Electromechanical	Mouth	2150€

The proposed device emulates an USB mouse so it can be used with any computer, tablet or, even, smartphone. Moreover, there's no particular software installation, and, to make it cheap, i.e., under 100€, it is released as a DIY project open to even electronics or computer unskilled-people.

The accelerometer-based computer mouse

The idea of the work is to provide the information for anyone motivated to build a hands-free mouse for someone else needing it. Such information includes the bill of materials for the proposed device, instructions to build it, including how to embed the control program, and the user's guide. Before detailing the previous aspects, we shall comment how this device works.

Principles of operation

To make the device simple and easily mountable on any flat surface of a headphone or an earphone set, only one accelerometer is used.

By using a single accelerometer it is possible to obtain its (x, y, z) position. For accelerometers on the head, (x, y, z) ranges are quite narrow. For instance, a nodding movement gave a maximum span of 63 units for the X axis (see Fig. 2), and the maximum spans for tilting to the left or the right (see Fig. 3) were of 32 and 39 units, respectively, at the Z axis.

These ranges make it difficult to accurately translate head position to cursor location in screen coordinates. In fact, the first experiments with the device had proven that this mapping is only suitable for trained people that have good control on head movements.

However, while this might be interesting for some applications, it is not the case for mouse emulation.

Mimicking mice implies translating accelerometer position shifts to (x, y) displacement units. In this case, head tilting will be converted into vertical cursor movements, and nodding into horizontal ones.

Figure 2 shows that only one accelerometer axis changes significantly when moving the head up and down. Consequently, it is the axis to be used to obtain the y displacements for the cursor.

*Figure 2. Recorded accelerometer values for an up-down head movement.
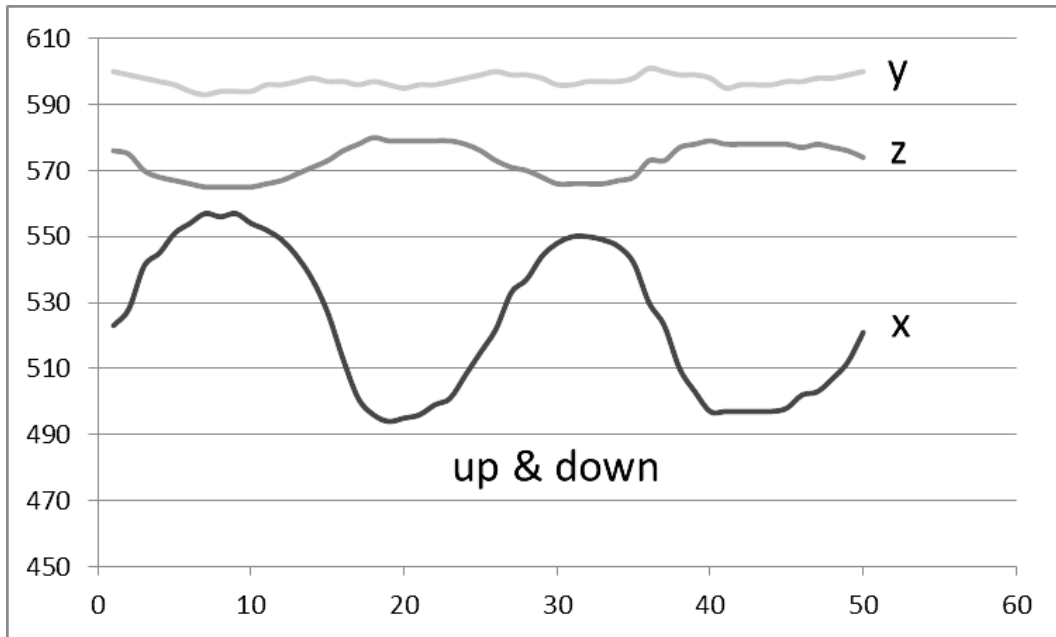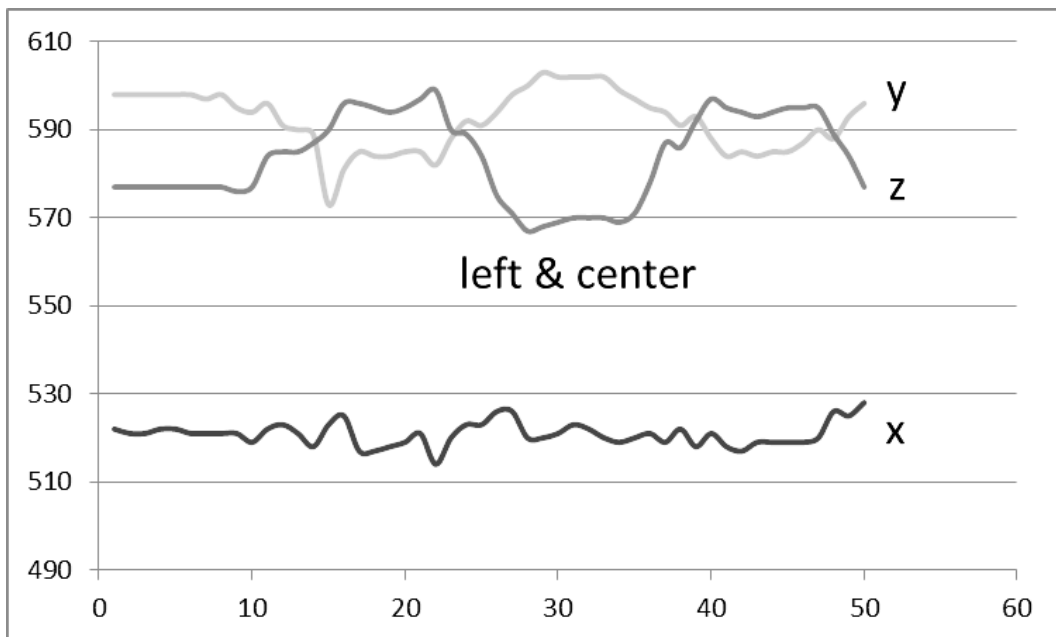Source: Authors.*

Figure 3 shows that the Z-axis data from the accelerometer is the one with the maximum sensitivity to head tilting, even this sensitivity is lower when leaning the head leftwards because the accelerometer is mounted in the left earphone.

*Figure 3. Recorded accelerometer values for left and right head tilting.
Source: authors.*

a)Left

b)Right

Because the accelerometer can be mounted with different orientations and at different places around the head, accelerometer data ranges for head movements must be computed before any mapping to mouse (*x*, *y*) data and actions are done. This implies that the device requires a setup procedure for proper calibration of the mapping methods before being usable.

Mapping accelerometer data to mouse movements and actions is performed by first mapping them into a 2D space *M*. For the test devices,

$$(x, y)_M = ((z-z_{min}) /(z_{max}-z_{min}), (x-x_{min})/(x_{max}-x_{min}))_{accelerometer}$$

where maximum (z_{max}, x_{max}) and minimum (z_{min}, x_{min}) values are determined by calibration.

Any change in the position of the accelerometer is recorded as a change in the position of the map *M*. To filter out 'mouse movements' that cause unwanted cursor movements on the screen, only centrifugal movements on *M* are translated into mouse position shifts or mouse actions.

Abscissas in Fig. 4 correspond to one coordinate in *M* (*x* or *y*) and ordinates, to the normalized mouse shift counts values (horizontal or vertical) in the

range [0, 1]. Note that the correspondence function forms a hysteresis loop, as it depends on the former values to know the direction of the movement.

Figure 4. Hysteresis of the mouse (x, y) functions with respect to the normalized 2D accelerometer position. Source: authors.
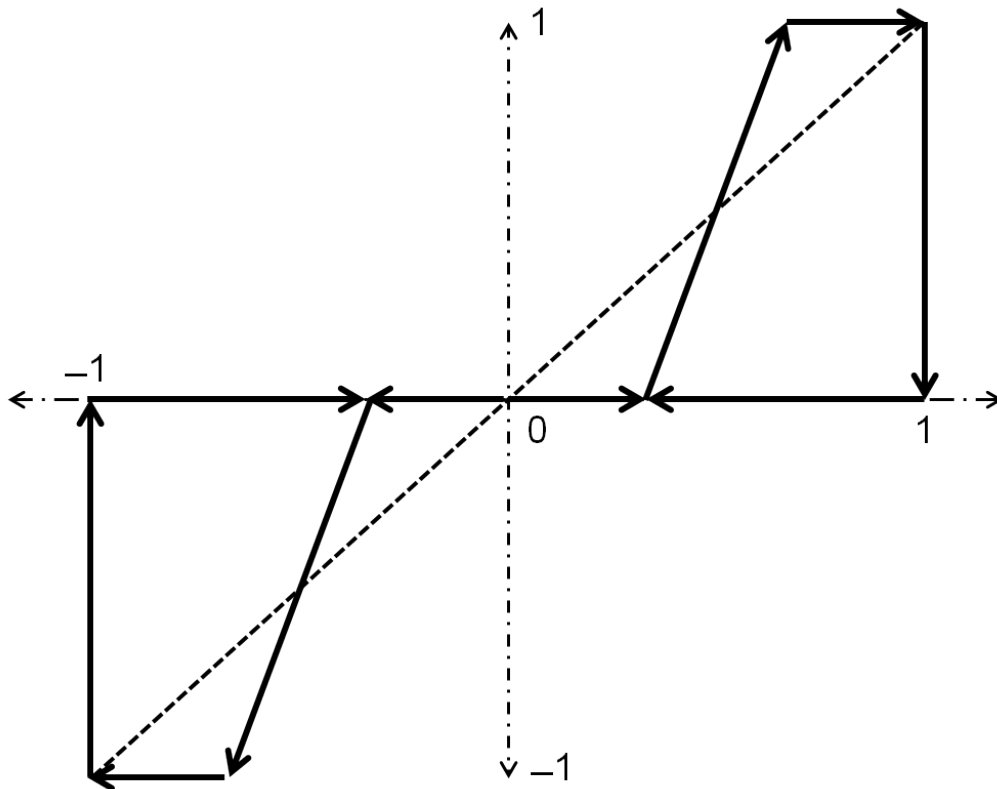

The idea is that the user only moves the cursor when pushing it. The more outwards, the more rapid it goes, up to a maximum. When he or she moves his/her head towards the resting position, the cursor stays still. Note that there is a region around the center where changes in $(x, y)_M$ are mapped to (0, 0), i.e. not taken into account. This makes it easy for users to keep the cursor still at a position on the screen.

In fact, keeping the pointer still for a while is the way to tell the device's embedded software to start a gesture-interpreting routine that checks the changes on $(x, y)_M$ to generate mouse actions. If no change is detected after a short period, it returns to the main "map-to-mouse-x-y-counts" translation routine.

Bill of materials

In order to build the device, you need to buy the material, which includes a pair of earphones, an accelerometer and an Arduino board (Fig. 5). Typically, all materials cost less than 80€.

Figure 5. Already built earphone mouse kit. Source: authors.
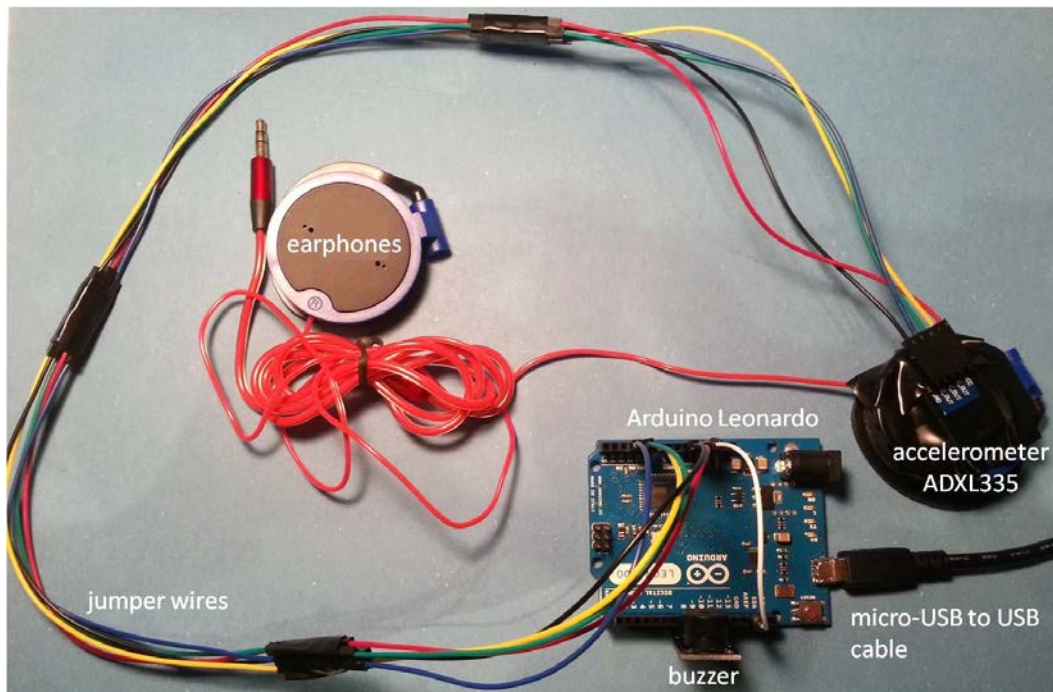
The Arduino Leonardo board processes the data from the accelerometer about the head movement and transforms them into mouse movements and actions. A buzzer is required to emit sounds to help the user during initial calibration of the device and to indicate when gesture recognition is on. The board connects to computers through a standard USB to micro-USB cable.

The accelerometer ADXL335 (board GY-61) is used to detect head movements. This very board can be directly powered from the Arduino board because it includes a voltage regulator on its own. Therefore, jumper cables link it with the Arduino board for power supply and data transmission.

The earphones are used as a support for the accelerometer and can normally be used, too.

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Apart from the previous component set, scissors and insulating tape are the only extra elements to build a mouse.

Assembly guide and software installation

The first step is to attach the accelerometer board to one of the earphones with the tape, and the last one consists of programming the Arduino board. In between, jumper cables have to be connected among them to form longer cables that connect the Arduino board with the accelerometer, and the buzzer must be mounted.

To program the Arduino board, people must go to the Arduino's official web page to download the appropriate software, and to the earphone mouse web to download the program to be embedded into the Arduino board.

The device shall be ready to use when a message saying "download complete" appears on the Arduino programming application.

User's guide

Upon connecting the earphone-mounted mouse to a PC, it starts a calibration procedure. After that, the device is ready to emulate a mouse controlled by the head movements.

Calibration

The calibration procedure determines head movement range and is required to correctly interpret the gestures that will become mouse actions. It is automatically done every time the device is plugged.

An accompanying person, possibly the same that has put the device on the user, must wait until the calibration process is completed. Take into account that in case of an incidence, the device must be reset. Once the calibration is correct, the user can continue to use it in a fully autonomous way.

The procedure is quite simple: the user has to keep his/her head in a rest position for 5 seconds, then lean it to the left for 5 seconds more and, finally, lean it to the right for other 5 seconds. Every step ending is signaled

by a sound from the buzzer and by a blinking LED on the board. (The 5-second wait has been experimentally determined to be OK, but can be changed by re-programming the device with this value changed: it is one line of code, only.)

Figure 6 illustrates the calibration procedure by using smileys. The strip describes, step by step, what users should do by following the action shown by the smiley at every frame. The loudspeaker icon stands for hearing a buzz and the chronometer, for waiting a period of time in the smiley's position.

Figure 6. Calibration procedure. Source: authors.

Note that the rest position is the one in which the user feels comfortable looking at the screen. The movements and actions of the mouse will be achieved through the change of this position.

Operation

It is convenient to consider that this device has two operation modes: as a pointer and as a gesture interpreter. In the pointer mode, it transfers the head movement to the pointer movement on the screen. In the gesture interpreter mode, it transforms given head movements into mouse actions.

To switch from pointer mode to gesture interpreter mode you need to stop the pointer in the desired position. Each time the pointer stops on the screen, the buzzer module will emit a sound to show it. From this moment on, the user will have 2 seconds to make a movement that matches a mouse action. It is important that the head movement to perform the gesture starts when the sound is over.

If no motion is detected, the mouse will return to the pointer mode and the user will be able to move the pointer through the screen following the head movements. To do so, he or she must move the head towards the direction in which he or she wants to push the screen cursor, as shown in Fig. 7.

By default, the device is in the pointer mode.

In the gesture interpreter mode, the device senses the head movement so to produce the corresponding mouse action (see Fig. 8.)

All gestures involve moving the head from the resting position and going back to this position once finished.

Figure 7. Pointer mode options. Source: authors.
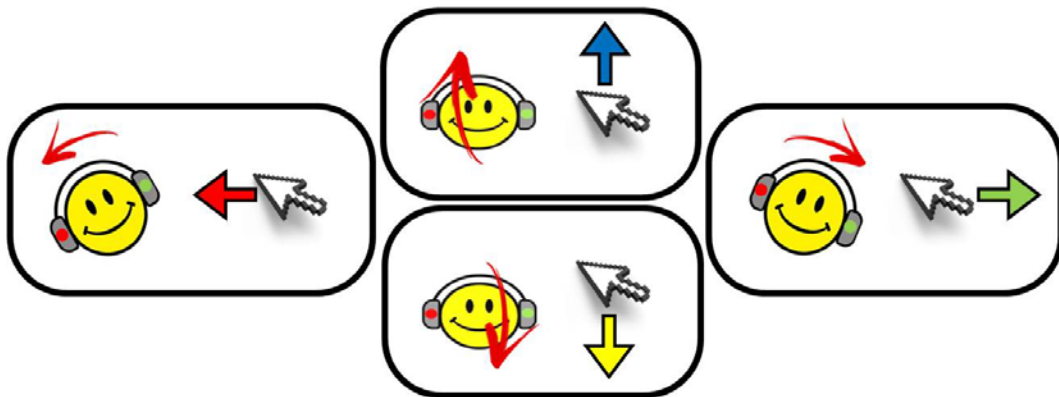
Single left and right clicks, which are the most frequent mouse actions, are obtained by tilting the head leftwards or rightwards (graphic instructions on top of Fig. 8.)

Holding the head leant to the left causes a double click (upper long strip in the middle of Fig. 8) and by holding the head leant to the right the click and hold for a dragging effect is obtained (lower long strip in the middle of Fig. 8.) In both cases, the user must return to the resting position when the action is achieved.

Figure 8. Gestures and related mouse actions. Source: authors.
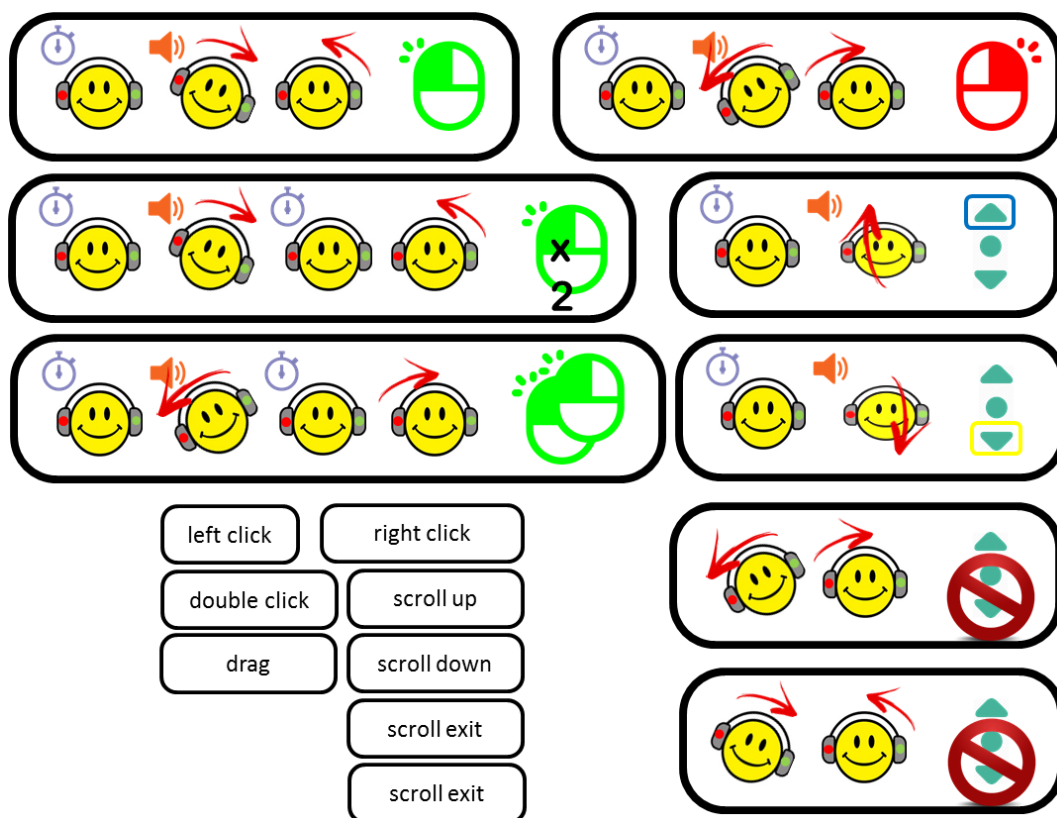
The gesture to scroll up or down consists of moving the head upwards or downwards (Fig. 8, middle right instruction strips.) Holding the head nodded up or down keeps the scrolling effect. To exit the up and down scroll movements (lower right corner on Fig. 8,) tilt the head to either side so that the device switches to pointer mode and the pointer starts moving again on the screen.

Results and conclusion

The aim of this work is to provide anyone in need for a hands-free mouse with an inexpensive, full-featured mouse. Particularly, it is addressed to special needs people so that they could have access to information technologies just as average people.

The proposed earphone-mounted, accelerometer-based, USB mouse has been designed to be like any other regular computer mouse, ready to use with any application on any platform.

The resulting device fully emulates a conventional computer mouse and it is the first of its class that does not require any specific driver or software installation.

In fact, this is one of the main differences with other devices such as the well-known SmartNav. The other is that it is an open device that can be built by following the instructions on the web http://www.earmouz.org, which also contains the embedded software to download, the user's guide, and complementary information about the project.

The device has been validated with a series of informal, empirical tests at exhibits and specialized centers. Tests consisted of asking users a few tasks like following a link on a web page already opened on the screen or opening an application just after being guided through the device setup.

The first round of tests with real devices had been carried out at our lab, at the Barcelona Mini Maker Faire (2014) and at a center that work with disabled people. People were asked to wear the device, guided through the calibration procedure and told how to use it. After observation of tests, they were asked to give their opinion about the device. At our lab and at the fair, all volunteers managed to use the devices after less than a minute but found some operations like scrolling and dragging a bit difficult.

In the case of the center for the disabled people, we found out that the version that mimicked the head movement was not suitable for those who couldn't control it (e.g. could not manage to click on an icon on the screen because they could not keep the cursor still) or who had to move it slowly. In fact, people suffering from nervous illnesses that led to hand impairment have several degrees of tremors that hinder the usage of any pointing device, including ours.

An added difficulty for testing the device with special needs' people is that, among the ones that can use some mouse-like device, most of them were already using one such device and were not keen to using a new one. Indeed, depending on their capabilities, learning how to use a new device is a long and hard process, hence something worth a second thought.

Anyway, we had taken their opinions into consideration for creating the second version of the embedded software, which changed the way the device worked from the head movement tracking mode to the "move-by-pushing" behavior. In this case, the user moves the head to virtually push the cursor on the screen up, down, left or right, and can make other actions (such as clicking, scrolling or dragging) by doing a virtual push within a few seconds after the cursor has been left still on the screen.

The second round of tests proved this last operation mode more tolerant to "movement noise" caused by tremors and to different head movement speeds. Tests have been carried out at the VI International Congress on Design, Research Networks and Technology for all, DRT4ALL (2015), as well as in private demos.

With this upgrade, however, casual testers got a bit confused at the beginning because they expected the cursor on the screen following their head movements. Anyway, once they were told about the "cursor pushing" mode, they adapted quickly and had fewer problems with mouse actions than with the former version. Therefore, the new one proved to be more easy-to-learn and robust.

Further improvements that were suggested by users include skipping the setup procedure and having an audible feedback of the mouse movements and actions. Consequently, we have plans to have a third version of the software to make calibration as seamless as possible and to provide users with sounds related to mouse operation. Anyway, all the information about the device is open so that anyone can adapt it to his or her needs. In the end, we expect that the proposed mouse can be helpful and improve the quality of life of its users.

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