Human-Computer Interface Based on IoT Embedded Systems for Users with Disabilities

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Abstract. This paper investigates how low-cost embedded systems can be tailored to support the interaction between users with disabilities and computers. The main idea is to implement several software solutions for assistive technology to deploy on the user embedded device. When such a device is connected to a whichever computing system (e.g. through an USB connection), it acts as HID (Human Interface Device) peripheral (e.g., mouse and keyboard), so that the user can work on the computer without any previous configuration setup to adapt the behavior of the computing system to the user disability. The proposed solution exploits Cloud-based services to adapt the device firmware to the user's needs and preferences. To test the whole system, we discuss the design of an alternative input device based on MEMS accelerometers and the Atmega32u4 microcontroller and it is currently intended for individuals with motor disabilities.

Keywords: Human-computer interface · Users with disabilities · IoT devices · Programmable embedded systems

1 Introduction

The Internet of Things (IoT) aims to interconnect everything into the Internet, from daily life devices to more complex networked systems exploiting global network infrastructures, linking physical and virtual objects, using Cloud computing resources, processing sensor data, and adopting advances communication technologies [2]. Here we consider IoT equipments based on programmable low-cost embedded systems and microcontroller boards which are currently available on the market. Some of these devices (e.g., the Raspberry Pi) come with a tailored Linux operating system able to execute pieces of software implemented in a high-level programming language (such as Python or Java). Generally, they also have an integrated network connection to access the Internet and exchange data with external smart objects. A classic deployment of these embedded devices implies that they manage heterogeneous wireless sensor networks and process data over the Cloud. Multiple application scenarios can be imagined for this approach [3,9]. This paper discusses a different approach to exploit Cloud computing for IoT purposes. It focuses the attention on how such IoT devices are able

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to interface a generic computer and to act as alternative input devices. Specifically, we discuss how a microcontroller board can support external sensors and peripherals in order to work as Human Computer Interface (HCI).

Typically, disable users interacts with a computing environment by means of personalized Assistive Technology (AT) hardware and software solutions. For example, users with motor disabilities cannot use standard keyboards or mouses and rely on alternative input devices (e.g., joysticks, switches, special keyboards, voice recognition systems) and mouse emulation software. Similarly, people with low vision work using screen reader programs to manage a Personal Computer (PC), or executing screen magnification pieces of software in order to better navigate a visual interface. Regardless the type of used AT equipment, such an equipment requires a specific configuration process in order to accomplish the end user's needs. This task has to be performed by an AT expert, who works close to the person with the disability in order to properly adapt the computing environment to its user. The configuration task has to be carried out on any user PC, and it can become an hard task on specific system, such as in an Internet point or in a laboratory, where the user cannot install tailored pieces of software or drivers. In general, a very difficult situation occurs every time an user has to work on a computing environment that does not support his/her personal assistive solutions.

To address the aforementioned issues, we suggest to provide the end user with a smart AT hardware device, that is an IoT embedded system able to interface the user with any computer without any installation of drivers or specific applications. To this aim, the device includes a specific firmware to interface sensors and other AT standard devices (e.g., reduced keyboard or special mouse), converting the produced input data into native input command for a computer. Therefore, if the disable user is usual to work with specific AT tools (e.g., voice recognition application, webcam-based eye tracker), our solution allows him to use the same AT equipment to interact with different computing devices, such as PCs or smartphones. Such embedded system has a built-in wireless network interface and its functionalities can be customized using a Cloud-based service. This is an important feature, since a remote AT expert may support a user by updating the firmware on the embedded HCI platform he/she is going to use to access a computer.

The aforementioned setup process needs to be performed only once and it will make accessible any computer able to interact with the HCI system. To show a concrete adoption of an HCI, in the next sections we discuss the development of a prototype, based on a tri-axial accelerometer, working as mouse emulator for computer users with motor disabilities. The device has an Atmega32u4 microntroller with an USB device connection, while we use a different processor to run our software controller on a Linux embedded operating system.

The rest of the paper is structured as follows. Section 2 presents the architecture of the proposed HCI prototype and describes the configuration process based on Cloud services. Related works in the field of AT are presented in Sect. 3. Finally, conclusion and future works are summarized in Sect. 4.

2 HCI System Description

The proposed human computer interface consists of two key components. First, an Atmega32u4 microcontroller is required to appear as a native mouse (or keyboard) when the device is attached to a generic computer with an USB host port. More specifically, the same microcontroller executes a custom version of the Arduino bootloader that supports the Mouse/Keyboard libraries. Another main hardware component of our HCI system is a second processor allowing to boot a Linux embedded operating system equipped with a Python runtime. Therefore we use a standard Python high - level programming language to acquire and to process data from external devices and sensors. Additionally, our embedded system needs to manage a network connection to access the Internet and an USB host port able to interface external peripherals.

To fulfill these conditions, currently our prototype is based on an Arduino Yun board, a microcontroller board based on the Atmega32u4 and the Atheros AR9331 procesor which supports a Linux distribution based on OpenWrt named Linino. The board has built-in Ethernet and WiFi support, a USB host port, micro-SD card slot, 20 digital input/output pins and a micro USB connection for connecting a computer. Moreover, the YUN itself from other Arduino boards in that it can communicate with the Linux distribution onboard, offering a powerful networked computer with the ease of Arduino. In addition to Linux commands like cURL, the Atheros processor is able to execute shell and Python scripts for robust interactions.

From a technical point of view, we have interfaced the Yun board with several kinds of sensor node, available on the market. Each sensor node consists of an accelerometer, a dedicated microcontroller, and an interface which enables the communication with a computing device, like an embedded system. This interface can be a wireless (bluetooth or zigbee) or wired. Sensor nodes can be powered by using a coin cell battery or a rechargeable battery. So, these devices are very small and non invasive; for example, they can easily be attached on the head. Furthermore, this hardware solution does not impair the natural movement of the body: examples of possible placements of the sensor nodes are given in Figs. 1 and 2.

Here we focus on head movements, since the head is the highest body segment and in consequence, the last affected in spinal cord injury patients. Additionally, many people are unable to use a standard computer mouse because of disabilities affecting their hands or arms. Head controls offer one alternative by allowing people to use head movements to control the computer cursor. Human head-movements can be characterized in movements for any other two dimensional device. By using an accelerometer attached on the head, we are able to detect four kinds of movements, as described in the Fig. 3.

2.1 The Mouse Emulator

According to the proposed mouse emulator, the movements made with the hand to move the mouse pointer are substituted by head movements. Specifically, up

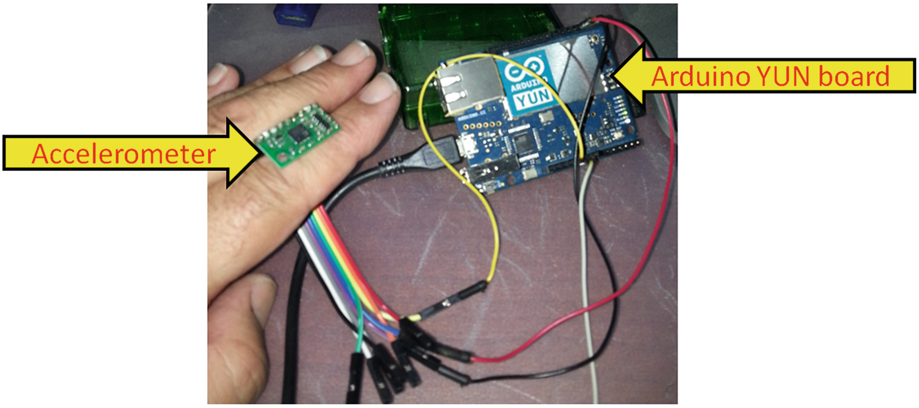

Fig. 1. Arduino Yun and an accelerometer-based sensor node placed on a finger.

Fig. 2. A wireless accelerometer-based sensor node attached on the head. In this case, it is connected to the Arduino Yun wirelessly.

Fig. 3. On the left, there is a roll head movement. On the right, there is a pitch head movement.

and down vertical movement (pitch) is used for up down displacement while roll movements are used for left right displacement. So the end user can fully control a computer: for example, he/she can use an on-screen keyboard. Such a solution provides also a novel interaction method for controlling a computing environment through very intuitive body movements given that a sensor node can detect measurement of inclination changes less than 1.0 °. This is a very important feature which can be a key element for independence and autonomy of people with disabilities: in these cases, enabling alternative and simple interaction with a standard personal computer becomes critical for these kinds of users.

Moreover, our HCI system is based on signal processing algorithms which enable to classify gestures: for these purpose we have marked two kinds of movements: fast and slow. A slow gesture features low acceleration values and it can be used for typical mouse pointer movement; a fast gesture features high acceleration values, so these signal peaks can perform click or double click events.

2.2 Configuration Process

Considering the Arduino YUN environment, all the algorithms for interacting with external sensors or devices have been implemented in Python. This also allows us to create a system service to synchronize all the applications and their options with a Cloud-based service. By using a simple web application running on each Arduino boards, it is possible to configure all the parameters of AT tools running on the board.These data are stored into a user profile available on a remote server. Such feature may allow a remote AT expert to support a user with a disability by adjusting the firmware running on the embedded system used by the person to access to a computer.

3 Related Works

AT can be viewed as technology used by individuals with disabilities in order to perform functions that might otherwise be difficult or impossible. AT can include mobility devices such as walkers and wheelchairs, as well as hardware, software, and peripherals that assist people with disabilities in accessing computers or other information technologies [5].

In this field, alternative input devices allow end users to control their computers through means other than a standard keyboard or pointing device. Examples include [1]:

- Alternative keyboards featuring larger- or smaller-than-standard keys or keyboards, alternative key configurations, and keyboards for use with one hand.
- Electronic pointing devicesused to control the cursor on the screen without use of hands. Devices used include ultrasound, infrared beams, eye movements, nerve signals, or brain waves.
- Sip-and-puff systemsactivated by inhaling or exhaling.
- Wands and sticksworn on the head, held in the mouth or strapped to the chin and used to press keys on the keyboard.

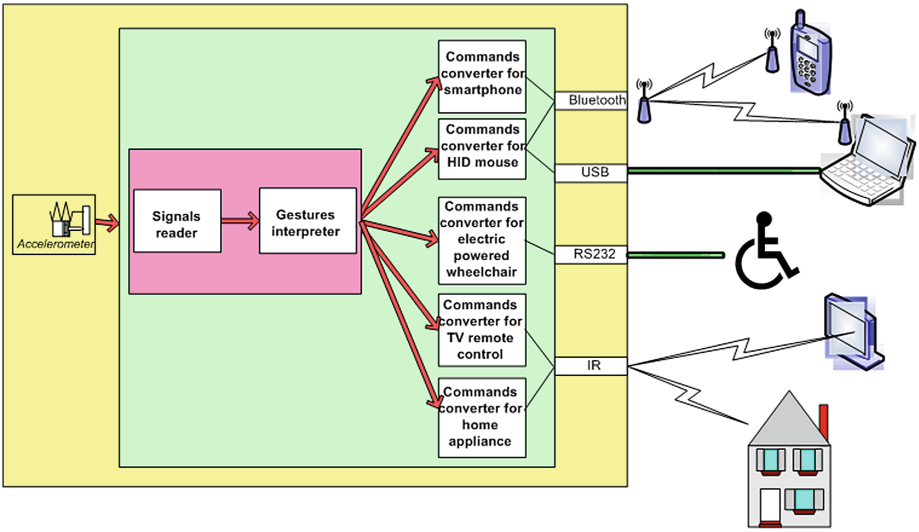

Fig. 4. Block diagram of an universal HCI system based on accelerometers.

- Joysticks manipulated by hand, feet, chin, etc. and used to control the cursor on screen.
- Trackballs movable balls on top of a base that can be used to move the cursor on screen.
- Touch screens allow direct selection or activation of the computer by touching the screen, making it easier to select an option directly rather than through a mouse movement or keyboard. Touch screens are either built into the computer monitor or can be added onto a computer monitor.

Several novel method for supporting the interaction between users with disabilities and computers are available in literature [7]. In [4], the authors describe a prototype based on RGB-D sensors able to support a multimodal human computer interaction and to replace some existing AT solutions. A particular tabletop keyboard is discussed in [6], it is mainly designed for stroke patients. EMG sensors can be used to design new types of HCI systems, as discussed in [10]. Also, interesting studies about BCI (brain computer interface) are available in [8].

4 Conclusion

This paper dealt with the usage on embedded systems and IoT devices in order to achieve alternative human-computer interfaces for users with disabilities. The proposed solution exploits Cloud-based services to adjust its functions according users' needs and preferences. To demonstrate a possible usage of the HCI system, a mouse emulator has been developed using an Arduino YUN with a MEMS accelerometer sensor.

The next version of the HCI system discussed in this paper will be based on the block diagram depicted in Fig. 4. Our software will relate recognized gestures with specific commands required to control external devices; the low cost sensor can detect a few of the movements, but they can fit to use computers, smartphones, televisions, cameras, robots, electric powered wheelchairs etc.

Also, the HCI will consist of three functional blocks:

- a signals reader collects acceleration readings;
- a gestures interpreter detects movements on the base of sensor values;
- a commands converter associates these recognized gestures with specific commands needed to control many devices.

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