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A new multisensor software architecture for movement detection: Preliminary study with people with cerebral palsy

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ABSTRACT

A five-layered software architecture translating movements into mouse clicks has been developed and tested on an Arduino platform with two different sensors: accelerometer and flex sensor. The architecture comprises low-pass and derivative filters, an unsupervised classifier that adapts continuously to the strength of the user's movements and a finite state machine which sets up a timer to prevent involuntary movements from triggering false positives.

Four people without disabilities and four people with cerebral palsy (CP) took part in the experiments. People without disabilities obtained an average of 100% and 99.3% in precision and true positive rate (TPR) respectively and there were no statistically significant differences among type of sensors and placement. In the same experiment, people with disabilities obtained 97.9% and 100% in precision and TPR respectively. However, these results worsened when subjects used the system to access a communication board, 89.6% and 94.8% respectively. With their usual method of access-an adapted switch- they obtained a precision and TPR of 86.7% and 97.8% respectively. For 3-out-of-4 participants with disabilities our system detected the movement faster than the switch.

For subjects with CP, the accelerometer was the easiest to use because it is more sensitive to gross motor motion than the flex sensor which requires more complex movements. A final survey showed that 3-out-of-4 participants with disabilities would prefer to use this new technology instead of their traditional method of access.

1. Introduction

Communication is vital for human beings. Great benefits could be reaped from a system allowing people with severe disabilities to access a computer or a communication system reliably, with little effort and quickly. There are several devices on the market, together with scientific papers which translate user intentionality into events. The simplest and most commonly used is based on a mechanical switch. There are several versions of this mechanical switch which depend on the user's level of movement. Thus, there are switches that can be operated by head movements (by pressing the switch with the cheek, head, chin), or by moving the arms, legs, hands, tongue, etc.

Most organizations that care for people with disabilities use such devices on a massive scale so that they can use software applications, particularly those based on scanning methods, by simply connecting the switch to an adapted device which translates user movements into software selections (mouse clicks, enter keystroke, etc).

For people with severe disabilities, these simple devices are still very difficult to use. For this reason, there is a need for devices capable of translating weak intentional movements, without the subject having to target the place where the switch is. We investigated two of these possible devices: accelerometer and flex sensors.

1.1. Accelerometer

Several devices can be employed to detect movements. One of the best known and widely used is the accelerometer. Single- and multi-axis accelerometer models are available to detect magnitude and direction of g-force as a vector quantity, and they can be used to sense orientation, coordinate acceleration or tilt detection. Placing accelerometers on limbs allows us to assess locomotor skills Masci et al. (2013), Palmerini et al. (2013), Yoneyama et al. (2013, 2014), track joint angle El-Gohary and McNames (2012), Chirakanphaisarn (2014) or evaluate recovery after an injury Hurd et al. (2013) or stroke Pas et al. (2011). Accelerometers have also been used to assess movements of people with cerebral palsy who typically have abnormal muscle tone,

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muscle weakness, primitive reflexes or uncoordinated movements. The assessment of physical activity in this population is important for the design and implementation of health, therapy and physical education programs. In Capio et al. (2010), the use of inertial units appears to be a valid instrument for measuring raw activity volume and it is suitable for use in studies attempting to characterize the physical activity of this population. Wearable inertial sensors have also been applied to allow people with disabilities to access a computer. In Raya et al. (2010) an inertial mouse driven by head movements is reported. The accuracy of such a device is about 1° and experimental results with two infants with CP (athetoid and dystonic cases) demonstrates that the children are able to place the pointer near the target but they find fine motor control difficult. In Ranjan et al. (2010) a universal remote control based on an accelerometer is shown. It can be placed on the hand or wrist and it detects four movements: hand up, down, left and right in order to drive an infrared transmitter to control a TV set. Although the movements are easy to execute for a subject without disability, for some people with CP they are very difficult. In fact, the authors do not report experiments with such users. Accelerometers are important devices for detecting intentional movement even in subjects with severe motor problems. The simplest way to use them with such people is putting them on the limbs or head to convert weak movements into switch strokes suggested in Mariano et al. (2014), but the authors do not report any tests with people with disabilities.

1.2. Flex sensor

Another device used to measure or detect movements related to joint bending is based on a flex sensor Saggio (2012, 2014). The flex sensor changes its electrical resistance value depending on the amount of bend it is subjected to. This sensor can be implemented with different techniques. The one most commonly adopted is based on a resistive film element which may consist of a polymer printed on a plastic substrate Tongrod et al. (2010), a conductive elastomer in an elastic fabric Tognetti et al. (2006) or more recently linear potentiometers and flexible wires Park et al. (2014). This technology has been used to measure joint angle Bakhshi et al. (2011a), for example, knee flexion using a supportive cloth in which the flex sensor is embedded. However, in another paper, the same authors, show how inertial sensors units can be used for the same proposal to measure bending angle Bakhshi and Mahoor (2011a) with improved accuracy. Flex sensors can be placed in gloves to detect finger flexion. These sensors can be combined with other kinds of sensors such as contact sensors and/or an accelerometer in the same glove to recognize hand gestures such as Sign Language fingerspelling Tanyawiwat and Thiemjarus (2012), Nelson et al. (2013), Ibarguren et al. (2010), Adnan et al. (2012). Controlling fingers as in fingerspelling is an impossible task for many people with disabilities. They require simpler gestures. In Nelson (2013a) a wearable multi-sensor gesture recognition system is proposed for people with disabilities. The system is based on an electrooculography capture system to detect eye movements by using a textile sensor in a headband and a glove with flexometers and an accelerometer to detect hand gestures. Hand gestures are made by pointing a single finger or a set of fingers from their bend position. Although hand gestures are simpler than in other reviewed articles, people with disabilities still find them difficult to perform. Moreover, putting a glove on is not easy for subjects with muscle stiffness, joint atrophy, etc. such as those with CP. A much simpler system using bending detection on one finger would be easier for such subjects to attach and use.

1.3. System goals

A system that translates weak movements into signals would not generate very high peaks on the signal. Therefore, detecting those peaks, even in situations when the subject is tiring and using less force, is an important challenge for the system and enhances user interface interaction Mezhoudi (2013). Another issue is that intentional movements are sometimes accompanied by uncoordinated movements, which therefore means the signal has several peaks. Although such peaks would be detected as movements, they should be considered as parts of the initial voluntary movement. As soon as the signal has been stabilized, which means that the movement has stopped, the detection of a new voluntary movement will be enabled again.

1.4. Mutilayer architecture

To accomplish these goals, in this article we propose a layered software architecture which can be implemented on external hardware platforms working as if they were mechanical switches, or on a computer.

We tested this architecture using both accelerometers and flex sensors in people with and without disabilities. Each layer can be adjusted by using parameters such as filter length, timeouts, etc, and one of our goals is provide a set of parameters allowing users to operate the system reliably.

Some related work about flexible and layered software architecture can be found in Beuvens and Vanderdonckt (2012a, 2012b) where the authors present a structured method for facilitating the integration of gestures in graphical user interfaces and in Molina et al. (2011a), where the authors propose a system based on infrared light to translate eye movements, blinks, winks or head movements into a set of events that may be configured to emulate mouse actions. The versatility of such a system is constrained to the usage of infrared light and even if it were possible to use such a system with other sensors, to do so, each layer would have to be reprogrammed. In Ibarguren et al. (2010) a layered architecture is also proposed for hand gesture recognition. Two layers are employed, the first, a segmentation layer, splits signals into movement and non-movement segments, and the second, a classification layer, assigns a character to each movement segment.

This paper is organized as follows: Section 2 presents the software architecture and the set of layers it is made up of. Section 3 describes the implementations chosen to test the architecture: Section 4 the methodology, including the system user profiles and how the experiments were conducted. This is followed by Sections 5, 6 and 7 with the results, discussion and conclusions, respectively.

2. Software architecture

The software as a whole receives data from the acquisition system and delivers commands to a computer to emulate a mouse click. To accomplish this main goal the software has been split into 5 different layers: the lowest is the hardware layer, which receives data from the analog to digital converter; the top layer is the finite state machine (FSM), from which events (mouse clicks) to the computer are dispatched Fig. 1. The data flow upwards from the hardware to the FSM layer, going through three other layers. Each one acts as a system receiving input data, then processing, and sending output data to the next layer in the data pipe. A queue between each two adjacent layers holds output data coming from layer number n before being accepted by layer $n+1$. A task manager is in charge of executing the processes on each layer as the queue connected at its input receives new data.