ELECTRONIC INTERFACE AND SIGNAL CONDITIONING CIRCUITRY FOR DATA GLOVE SYSTEMS USEFUL AS 3D HMI TOOLS FOR DISABLED PERSONS

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Keywords: Data glove, Human machine interface.

Abstract: A simple PC screen can be considered as an interface of a virtual environment where an user can move objects and interact with them. The interaction tools can be simply a virtual mouse or a keyboard. But it is evident how these tools cannot provide an immersive experience since the bi-dimensionality of the screen. So in the latter years the virtual reality is becoming more and more accomplished by new hardware interfaces capable to increase the realism degree. Among all, the sensorized glove is becoming one of the more interesting and promising of these interfaces. Here we propose the electronic interface and signal conditioning circuitry we adopt as the most suitable for our developed data glove system. The same solution we adopted can be usefully extended for other specific systems that treat signals coming from sensors which read kinematics from disabled persons with reduced Range Of Motion (ROM) capabilities.

1 INTRODUCTION

Nowadays people with disabilities have the possibility to communicate with other persons via computers, but most of the peripherals (keyboard, mouse, tablet, ..) cannot be user-friendly for some disabilities. So new user input methods are welcome, especially the ones that can utilize the residual motor capabilities of motor disabled persons. Among all the new inputs methods, the data glove can result one of the more interesting and promising solution because it can take into account the specific needs of disabled users. Equivalent mouse commands can be provided by hand motions and real keyboard functions can be obtained virtually pressing the keys displayed on a computer screen, thanks to the movements of fingers measured by the data glove.

Figure 1: Data glove commands virtual keyboards.

In addiction such a data glove can furnish new computer interaction possibilities, since allows the user to interact in a virtual 3D space rather than mouse and keyboard which act in a 2D plane.

The *data glove* is basically a common glove but with the characteristic of being endowed with sensors by which it is possible to measure the flex-extension and abdu-adduction of finger movements, the wrist postures and the relative position of the hand in the space. Different kinds of sensors, based on different principles, can be adopted to this aim, such as accelerometers, gyroscopes, Hall effect based devices, piezoresistors and so on (Dipietro L. et al., 2008). Using the same kinds of sensors it is possible to measure the Range Of Motion (ROM) of practically any junction of the human body (wrist, knee, neck, elbow, ..) In any case the measured electric signals, coming from the sensors, must be then conditioned, recorded and sent to a receiver for further exploitation, so a wireless transmitter must be designed too. Finally the overall system has to provide real-time measurements of all electric signals coming from the sensing devices.

For the electronic interface and the signal conditioning circuitry it is desirable to perform the following features: a) measurement range of the electric values should be sufficiently large, b) the

Saggio G., Bocchetti S., Pinto C. and Orengo G..
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DOI: 10.5220/0003157402480253
In *Proceedings of the International Conference on Health Informatics* (HEALTHINF-2011), pages 248-253
ISBN: 978-989-8425-34-8

circuit should be robust, because of the noise which must be taken into account in wearable applications; c) structure needs to be simplified for small size; d) removable battery must be integrated; e) power consumption should be low, to get a longer service time (a continuous monitoring would be obtained without battery replacement or recharge) and f) comfort to wearers during common daily activities. This is why we report here a solution we adopt as convenient for the previous requirements for a data glove system.

We refer to our data glove as HITEG-Glove since our group name (Health Involved Technical Engineering Group).

Moreover we realized a virtual hand based video framework to have the possibility of a real-time and off-line analysis of all the measured values.

2 DATA GLOVE

The HITEG-Glove here presented is mostly based on bend sensors capable of measuring bending angles thanks to the piezoresistive effect by means of which their resistance value depends to the angle they are submitted.

We measured performances of several bend sensors, manufactured by Flexpoint Sensor System Inc. and Image S.I., different in lenght and encapsulation materials.

Sensors resistance variation vs. bending angle is measured thanks to an home-made set-up based on a hinge where the sensors lay on, and a stepper motor which provides the rotation of one wing of the hinge (with respect to the other which is fix constrained) simulating a human finger joint rotation (see Fig. 2).

Each sensor can be characterized in a -90° to 180° (from inward to outward) angle range for programmable step value of bending angle, number of measurement repetitions and mechanical actuator speed. At known angles, the resistance values of the sensors are measured by an Agilent 34405A multimeter.

Among all the performed measurements, some relevant results are showed in Fig. 3. It reports measurement results, resistance mean values and standard deviations, on 6 different 2 inches length polyimmide encapsulated Flexpoint sample sensors: each sensor is characterized repeating measurements 10 times, varying bending angle from 0° to 120° and return.

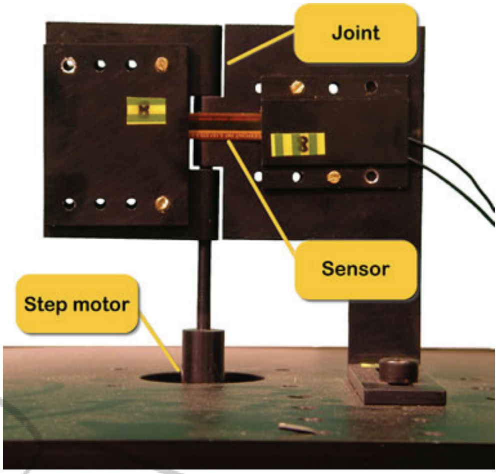

Figure 2: Experimental set-up for macroscopic bending measurements: it is designed to permit testing of a single sensor, simulating the real human finger joints kinematics.

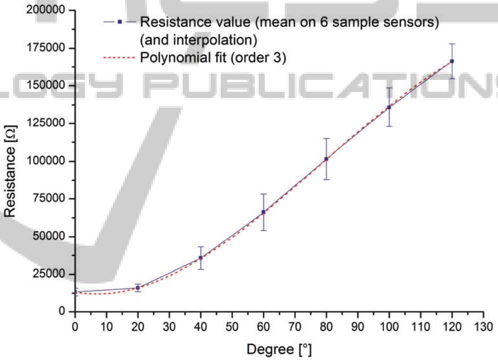

Figure 3: Resistance variation VS bending angle: mean on 6 sample sensors and standard deviation.

After the characterization, the sensors are mounted on a Lycra based glove, each corresponding to a single finger joint.

Figure 4: Lycra - based HITEG Glove.

3 SIGNAL CONDITIONING

In this paragraph we analyze the optimized electronic interface for our HITEG-Glove, according to the afore-mentioned conditions listed in the introduction. A novel approach for analog signal conditioning before A/D conversion, which matches the requirements is presented. System configuration, accuracy and resolution have been analyzed in-depth and designing rules have been defined. Experimental results show that this electronic interface exhibits less than 1% error in a large measurement range for strain sensor rotation angle. It also shows a good stability to power supply interference. The interface has been successfully applied to a glove-based measurement system of hand gesture.

Resistive bend sensors are integrated in clothing to acquire wearer's posture and movements in the form of voltage signals. They are interestingly light, soft and environmentally stable.

Piezoresistive sensors have been extensively investigated with some promising ones being explored for real applications (Saggio G. et al., 2009 - Orengo G. et al, 2009). They have a large measurement range for outward bendings from 0° to 120°, and correspondingly the resistance normally changes from 10 to 170 kΩ. The hysteresis they manifest is really negligible and repeatability is exceptional. Thanks to their high sensibility these sensors can be adopted as a key-element for measuring ROM of people with reduced hand capabilities. A second key-element is our proposed electronic interface and signal conditioning circuitry. The optimized electronic interface for wearable sensors here concerned is based on a differential instrumentation amplifier. Fig. 5 shows the proposed electronic interface.

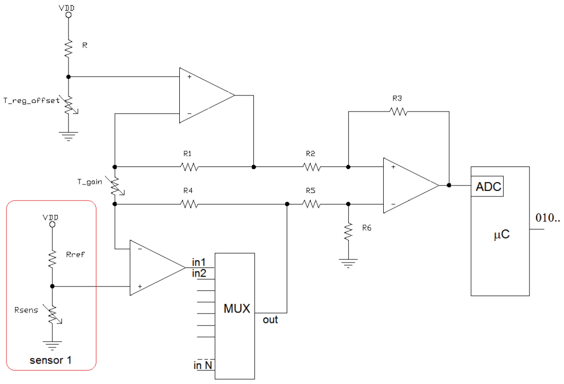

Figure 5: Signal conditioning electronic interface proposed.

It consists of a group of voltage dividers for resistive sensors (one for each sensor) to extract a voltage signal from sensor resistance variation using a first stage input buffer. Subsequently a second stage provides to properly shift/amplify the sensor signals with the possibility of finely adjusting both gain and offset level to make the levels of output voltage dividers fit the input range of a PIC microcontroller 12 bits A/D converter. In this way we can measure very little signal variation corresponding to very little joint bendings on disabled subject. Then the microcontroller can send the digital signals in a serial format to a general purpose PC for post elaboration, reconverting them to the corresponding bending angles of the joints.

Voltage dividers are used because of their simple structures and potential high dynamic measurement ranges they can furnish. In order to minimize the size of the electronic interface, a single conditioning circuit of the signal, which can be used by every sensor implementing a polling routine on a multiplexer, has been reasonably designed. It is important to notice that the voltage signal variation range can change from sensor to sensor; this is because the technological process of factory doesn't produce identical devices (as it results clear by observing the standard deviation reported on the 7 calibration points of the characteristic curve reported in Fig. 3). Another reason is that the maximum bending angle of each sensor depends on the joint it is applied to; for example the sensors of the proximal interphalangeal joints, which perform the maximum bending angle possible (typically 120° but in a wholly able subject), react with the largest resistance variation.

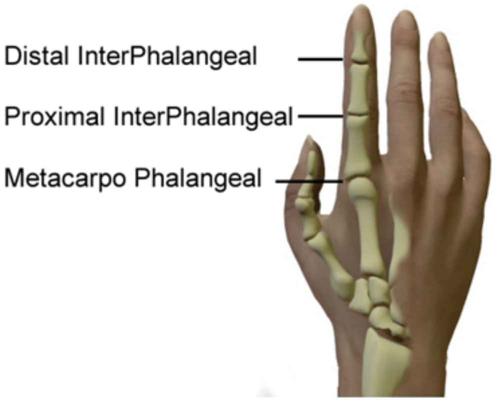

Figure 6: Human finger joints.

For such reasons it is necessary to choose in the design of the instrumented differential amplifier a voltage gain (and a level shift) so to realize the best match in order to make the signals of all the sensors fit the input range of a PIC microcontroller A/D converter. Considering a single voltage divider (represented in the box left below in Fig. 5), a meaningful issue in the design is how to set R_{ref}. The single element has the following voltage divider:

$$\frac{V_i}{V_{cc}} = \frac{R_{sens}}{R_{ref} + R_{sens}} \tag{1}$$

So, after a 120° bending:

$$\frac{\Delta V_i}{V_{cc}} = \frac{R_{sens\_max}}{R_{ref} + R_{sens\_max}} - \frac{R_{sens\_min}}{R_{ref} + R_{sens\_min}} \tag{2}$$

where R_{sens_min} corresponds to 0° bending, whereas R_{sens_max} to 120° bending, which is the maximum allowable flexion of a finger joint and ΔV_i to the consistent voltage variation.

In order to maximize the signal sweep for the maximum allowed flexure degrees even for people with a reduced ROM (which can be even much less than 120°), the voltage divider resistance R_{ref} can be yield nullifying the corresponding partial derivative:

$$\frac{\partial}{\partial R_{ref}} \frac{\Delta V_i}{V_{cc}} = \frac{R_{sens\_max}}{(R_{ref} + R_{sens\_\max})^2} - \frac{R_{sens\_min}}{(R_{ref} + R_{sens\_\min})^2} = 0 \tag{3}$$

to obtain:

$$R_{ref\_opt} = \sqrt{R_{sens\_max} R_{sens\_min}} \tag{4}$$

which corresponds to the geometric mean of the extreme sensor resistance values.

If the sensor bending sweep is not always the same, an optimized reference resistor for each sensor has to be chosen. The normalized voltage signal variation coming from each sensor becomes:

$$\frac{\Delta V_i}{V_{cc}} = \frac{1}{\frac{R_{ref}}{R_{sens\_\max}} + 1} - \frac{1}{\frac{R_{ref}}{R_{sens\_\min}} + 1} \tag{5}$$

$$\frac{\Delta V_i}{V_{cc}} = \frac{1}{\sqrt{\frac{R_{sens\_min}}{R_{sens\_\max}}} + 1} - \frac{1}{\sqrt{\frac{R_{sens\_max}}{R_{sens\_\min}}} + 1} \tag{6}$$

$$\frac{\Delta V_i}{V_{cc}} = \frac{1}{q^{-1} + 1} - \frac{1}{q + 1} = \frac{q - 1}{q + 1} \tag{7}$$

where:

$$q = \sqrt{\frac{R_{sens\_max}}{R_{sens\_\min}}} \tag{8}$$

The equation 7 provides the maximum voltage divider signal variation with the optimized value for $R_{ref-opt}$. Furthermore it can be seen that a strain sensor exhibiting the largest sweep in resistance for a given bending angle is required, because $\frac{\Delta V_i}{\Delta V_{cc}} \rightarrow 1$ for $q \rightarrow \infty$, even if this sensitivity is smoothed from the root.

This is the reason which led us to prefer in this project the Flexpoint bend sensors ($q^2=14$) over those from Image ($q^2=6$), as it is represented in fig.6, where the voltage divider sweep is plotted against the choice of the reference resistance for different q values.

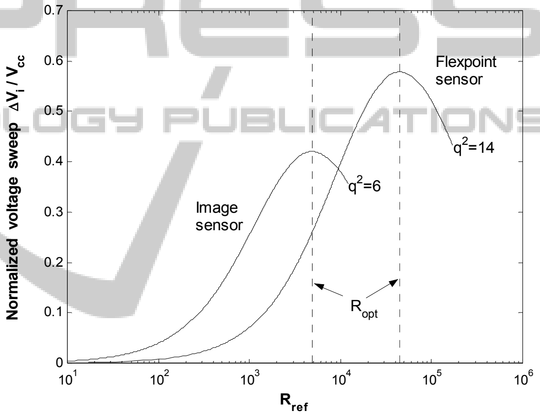

Figure 7: Normalized voltage divider output sweep vs reference resistor value.

Further investigation is required to set the appropriate resolution for the A/D converter inside the microcontroller. Naming V_n the noise coming from the signal conditioning circuits and V_{nq} the quantization noise, where:

$$V_{nq} = \frac{1}{\sqrt{12}} \frac{V_{cc}}{2^N} \tag{9}$$

it can be seen that the resolution N can be chosen from the following inequality:

$$V_{ntot} = \sqrt{V_n^2 + V_{nq}^2} < V_{LSB} \tag{10}$$

$$V_n^2 + \frac{11}{12} \frac{V_{cc}^2}{2^{2N}} < \frac{V_{cc}^2}{2^{2N}} \tag{11}$$

$$V_n^2 < \frac{11}{12} \frac{V_{cc}^2}{2^{2N}} \tag{12}$$

$$N < log_2\left(\sqrt{\frac{11}{12}\frac{V_{cc}}{V_n}}\right) \tag{13}$$

Since the rms noise measured at the output of the signal conditioning circuits is V_n=2mV, the above equation yields N<11.

On the other hand, to guarantee a one degree resolution for finger joints bending measurements, supposing a linear sensor resistance variation VS bending angle, the required number of bits is given by:

$$log_2\frac{V_{cc}}{\Delta V_i/120} = log_2\left(120\frac{q+1}{q-1}\right) \approx 7.1 \tag{14}$$

Since the embedded A/D converter has 12 bit, the above mentioned conclusions allow to calculate how many LSBs must be set to zero by the PIC.

4 VIRTUAL REPRESENTATION

Once data has been correctly acquired and converted into digital form, all values are sent to PC with a specific protocol useful to disambiguate and recognize the exact sensor under investigation (among all the 15 adopted, one at time) and its value. So the data are tidily stored in a specific database, one record for each sensor, one field for each recording time. In such a way data can be useful re-called and utilized in simple numerical format or, more effectively, utilized to replicate the real hand movement by a virtual avatar on a PC screen. With this aim, it has been realized a Graphic User Interface (GUI), programmed in C++ language, by means of Windows Application Program Interfaces (API) and DirectX 9.0c. The overall software converts digital values into bending degree values for each finger joint and it represents all postures on a graphical body model. A complete 3D body model was realized starting from Blender, which is an open source multiplatform software. In order to animate the model mesh and make it move, translating real human actions to virtual actions in the simulated environment, we defined an armature which is made of a series of invisible bones connected to each other via parenting or constraints, that allow us to pose and deform the geometry that surrounds it, in this case the mesh.

The armature is used for building skeletal systems to animate the postures of characters and anything else which needs to be animated (see Fig. 8, A and B).

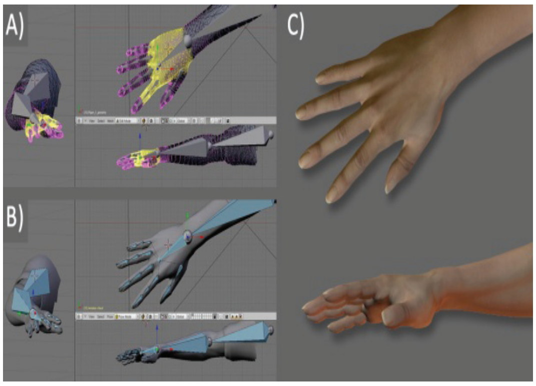

Figure 8: A 3D human hand model: A) Mesh with vertex group (yellow selection); B) Armature: hidden hand bones; C) Final rendering of the rigged model with textures and lights.

The armature modifier allows objects to be deformed by bones: as a bone moves, it deforms or moves the vertices (single points of a mesh) associated with it. The mesh surface is analogous to the skin of the human body. The armature is also called Skeleton. There are various great advantages from the utilization of 3D virtual model of the hand.

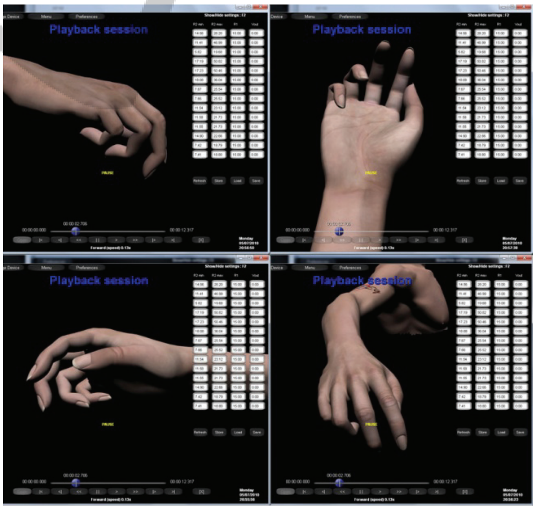

Figure 9: A reproduction session: software allows user to see an acquisition session off-line, and by rotating 3D model in any direction, it is possible to analyze reproduction from different viewpoints.

During the pre-processing data phase, the model has been utilized as a support tool to qualitatively verify the measurement repeatability. During the real-time visualization phase, the model allowed the hand visualization from different points of view, a continuous monitoring of the coherence of data streams and a rapid re-calibration if necessary.

During the post-processing data phase, thanks to the model, it was possible to replay all the fingers movements in slow / rapid / frame-by-frame motion and to isolate even just one finger at a time, removing the others from the view, in order to focus the operator's attention only on some important details.

5 CONCLUSIONS

Electronic interface and signal conditioning circuitry was developed and optimized to allow persons with a reduced ROM to have an easier Human Computer Interaction. In particular the interaction is obtained by means of a data glove which demonstrated to be one of the more interesting and promising of these interfaces, because it can take into account the specific needs of disabled users.

A framework of video-based virtual hand input for using one hand, provided an easy interface of a virtual environment where a disabled person can move and interact simulating a virtual mouse or keyboard. To increase the realism degree an immersive experience was allowed by the bi-dimensionality of the screen.

Our overall system is being tested on harm injured patients at the Hospital structure of the ASL Viterbo, Hand Surgery Dept., thanks to Dr. Antonio Castagnaro and Dr. Anna De Leo.

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