An Interface for Virtual Reality Applications

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Abstract: We present an input device for virtual reality (VR), which also has applications in tremor and respiration sensing in medicine. Moreover, we introduce an "environmental presence sensor" that can be used in a "virtual joystick." The joystick senses and tracks the position of the objects in the environment and allows controlling various actions accordingly. The main advantage of the device is the possibility to sense objects without any physical contact (hence the "virtual operation" capability). Moreover, the device interfaces with a personal computer (PC) like a standard joystick, with no need for any special hardware or software module.

Keywords: virtual reality, virtual joystick, medical application, respiratory and tremor signal, DSP

1. Introduction

In this section, we briefly overview a few specific topics related to interfaces for Virtual Reality (VR). Although it is considered still at its infancy, last years virtual reality has gained an extensive use in various fields, including training, education, entertainment, and medicine [1], [2], [3], [4], [5], [6]. Virtual Reality, as part of the information technologies, is a heterogeneous sum of tools and techniques applied to create an environment as close to the real one as possible. It generally involves computer based generation of *3D* visual, auditory, and tactile environments, and a set of interfaces, hardware and software tools that allow users to immerse, navigate, and interact with objects in the computer-generated environment. VR tools and techniques are rapidly developing in the scientific, engineering, teaching and medical areas. Among the applications of VR in medicine, the following have been reported in the literature:

* teaching aid, mainly in the fields of anatomy and physiology; for instance, use of anatomically keyed displays with real-time data fusion [3];
* modeling processes inside the human body;
* training the surgeons [3]
* Virtually experimenting surgery solutions before the surgery act (VR assisted surgery planning. [4]);
* functional movements analysis
* motion studies [7]
* ergonomics [3]
* rehabilitation studies (not yet as a true tool) [3],
* robotic surgery [2]
* remote surgery (telesurgery) [1],[8] telediagnosis;
* patient testing and behavioural intervention
* 3D reconstruction from tomography slices [9]
* diagnosis [10]
* psychotherapy [10]

Moreover, possible ways for direct emotion communication with virtual humans have recently been analyzed in [11]. Such a method of communication could be used, in the near future, in psychiatry.

Various interfaces are needed to make a computer operating for VR applications, including image and sound interfaces, actuators, force feedback etc. Besides *output* interfaces, *input* interfaces are needed. Presently, the main input interfaces are the sensing gloves and joysticks. In this paper, we present a new type of interface, the "virtual joystick", which can enhance the sensing capability in a virtual environment. The interface is based on a new type of proximity sensor [12], [13] and has been developed primarily in relation to medical applications [14], [15], in the framework of a VR system for medical applications (rehabilitation) [16], [17].

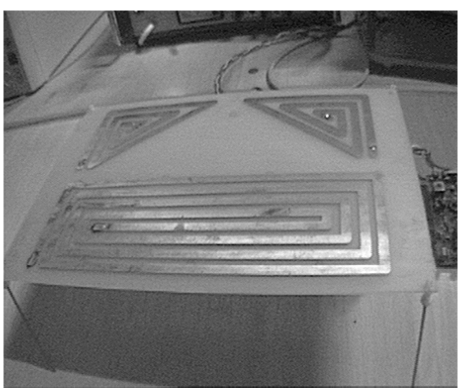
The proposed "environmental presence sensing" [18] and "virtual joystick" interface is able to sense the proximity, the movements and, when the joystick is referred, to track the position of the hand and to yield commands, similarly to a classic joystick. In the last application, the sensor system includes several (at least 3) sensors operating together to derive the position of the hand. The hand position commands the position of a controlled object, or a similar action, without any physical contact to the actual object. The sensor circuit may interface with a PC, like any normal joystick.

There are a large number of proximity sensor types on the market, with a large range of capabilities and applications. However, in many fields of applications, like virtual reality, bio-medical applications, robotics and industrial applications, no sensor meets all requirements. The recently proposed sensor family [12], [13], based on electrical impedance measurements, has demonstrated significant benefits in some respects. The potential application of this sensor covers the medical and VR fields, where such sensors with improved capabilities are needed [14], [15], [19] [18].

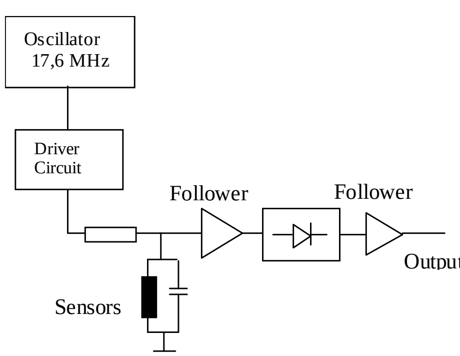
The organization of the paper is as follows. In the second section, the operation principle of the system is briefly reviewed. In section 3, selected experimental results are presented, along with exemplifying pictures. In the last section, we draw conclusions and speculate on potential applications.

2. Schematics and operating principle

It is known that an element generating an external electromagnetic field changes its impedance due to the properties of the objects in its close vicinity. The change is due to the change of the equivalent impedance (either reactive or resistive) viewed at the port of the measuring device. For the impedance change is high enough, one should excite the transducer with a high frequency signal related to the sensor properties.



(a) Sensor



(b) Block scheme of the sensor circuitry

Figure 1.

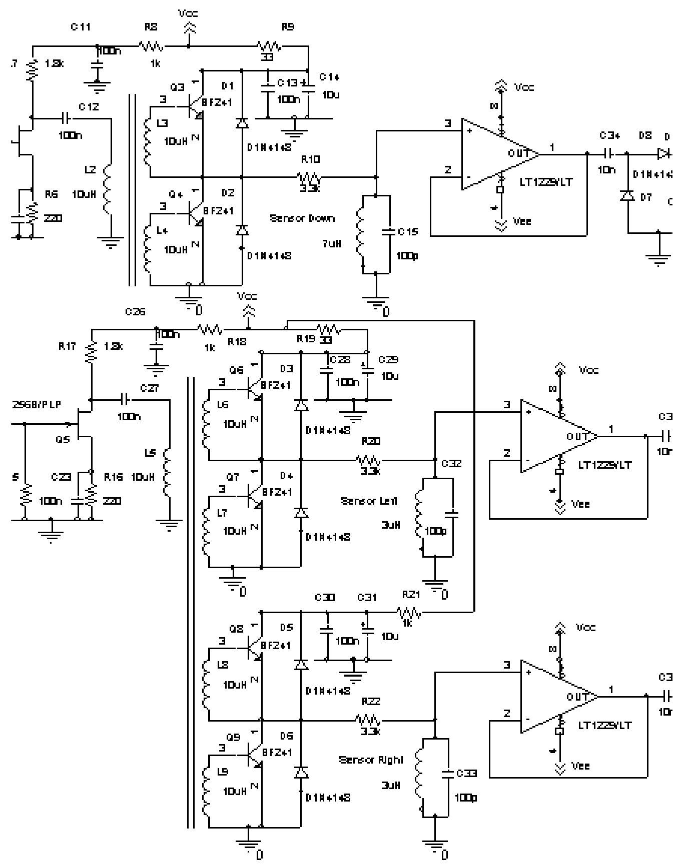


Figure 2. Part of the driving circuit.

According to [12], [13], the sensor is composed of a planar winding, the winding having a relatively large conductor width and a relatively small spacing between successive turns to achieve a suitably high capacitance between the turns and a suitably large overall capacitance for this resonant sensor. The winding is shaped to provide a relatively uniform electric field in a sensing zone that is generally determined by the overall dimensions and shape of resonant sensor. Such an electrical field is suitable for sensing dielectric (non-conductive and nonmagnetic) objects, as well as magnetic or conducting objects. Subsequently, we present the operation of the sensor according to [12], [13].

In contrast to conventional inductor/capacitor (“LC”) circuits that intentionally minimise “undesirable parasitic” capacitance and couplings to surrounding objects, the resonant sensor of the invention [12], [13] enhances the parasitic capacitance and the couplings and employs them as sensitive object-sensing elements.

The picture of the sensor and the general scheme of the circuitry used to drive this sensor are shown in Figure 1. The sensing element is a distributed RLC circuit that is turned to, or close to, the predetermined frequency of a driving oscillator. A resistor and the resonant sensor form a voltage divider circuit that generates at their junction a signal that is directly representative of a position and/or movement of an object in proximity to resonant sensor. The proximity of the sensed object to the resonant sensor produces a change in the parallel resonant frequency of the resonant sensor, which causes corresponding changes in its impedance and, therefore, the magnitude of the signal across the resonant sensor.

When the hand is above one of the sensors, the output of the corresponding circuit has a high value. Two paired sensors that sense the left-right balance are placed symmetrically on the board, such that the difference signal from the couple of sensors evidences the left-right movements of the hand. The principle is similar when detecting the forward and backward movement. The distance between the proximity sensor and the hand is another factor that can influence the magnitude of the output signal on the corresponding channel. It is used for a supplementary control.

In Figure 2, we present a scheme having two different channels (one of them driving two sensors). We need two driving circuits because there are two kinds of sensors, with different geometry and resonant frequencies. The three driving circuits are used to command the sensors, with three class D amplifiers. To obtain high Q factors for the resonant sensors and a good sensitivity, the voltage follower circuits use the current feedback operational amplifiers LT 1229 that have 100MHz bandwidth and high input impedance (25 MΩ, 3 pF.) The next stage is a rectifier circuit.

Before acquiring the signal, we use an ADC anti-aliasing filter realized with the *Max 296* circuit (figure 3) that is an 8th-order, low-pass, switched-capacitors filter that can be set up with corner frequencies from 0.1 Hz to 50 kHz. The *Max 296* is a Bessel filter that provides a response with low overshoot and fast settling. Since the *Max 296* has a linear phase response in the pass-band, all frequency components are equally delayed, preserving well the input signal appearance. The 8 poles provide 48dB attenuation per octave. For this kind of filter, the maximum recommended clock frequency is 2.5 MHz, producing a cut-off frequency of 50 kHz; the clock to corner-frequency ratio is 50:1. The TMS320F240 circuit symmetrically drives the CLK pin, on 50% duty cycle. The timer 1 in the DSP generates this clock signal with the help of associated compare register. To acquire the signal, we used the two 10-bit ADCs string/capacitors converter that are available on TMS320C240. Eight analogue inputs are provided for each ADC unit. For the three input channels, the ADCIN.7 and ADCIN.14, ADCIN.15 lines are connected and sampled with a 200 Hz rate.

After acquiring the signal, we pre-process it with a stop band filter, to remove power supply hum noise at 50 Hz. We use a FIR filter with 80-delay element, and Q15 format for storing and manipulate all the data. A second low-pass band filter removes the higher spectral component of the acquired hand

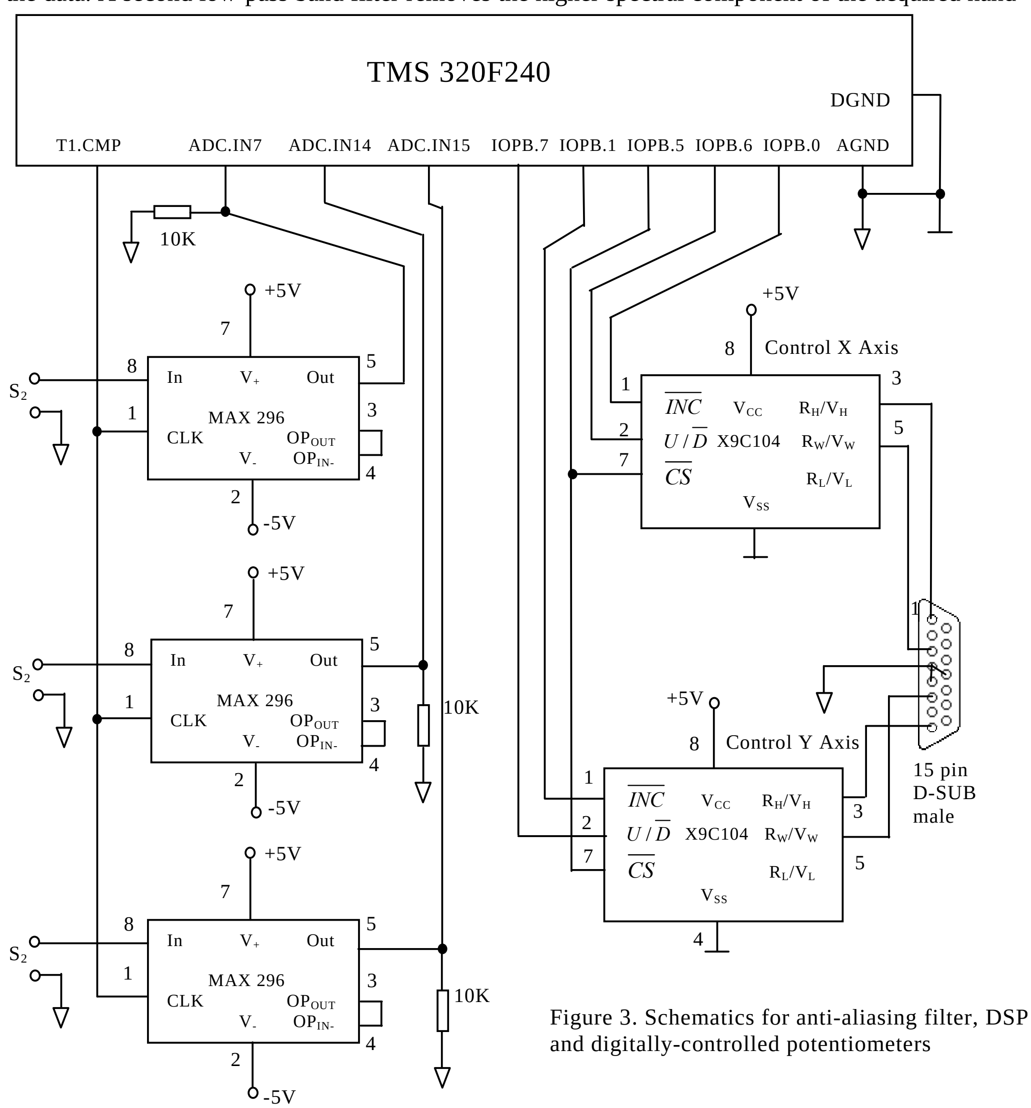


Figure 3. Schematics for anti-aliasing filter, DSP and digitally-controlled potentiometers

movement signal. In this mode, components like tremor are eliminated; for example, the movement of a pointer on the computer screen will be smoother. To detect the left-right, forward-backward and up-down movements, first we compare the difference between the output levels of all three transducers to sense the movements of the hand in the horizontal plane. In the next step, the actual values of all channels are compared with the last known result to sense the magnitude of the movements in the vertical plane. We change accordingly the value of the digitally controlled potentiometers generating clock and direction signals (up/down, increment or decrement the value of potentiometers) for X9C104 conforming to the requirement of this circuit.

Our goal has been to interconnect the sensor with a computer via a joystick port. Usually, the joystick port is not integrated in the motherboard of a PC, being implemented in multi I/O- or sound-boards. The connector of the port enables the control of two joysticks at the same time. Inside the standard joystick, the stick is attached to two 100 KΩ potentiometers, typically. One of the resistors changes its value according to the change in the position of the stick along the X-axis. The other potentiometer does the same for the Y-axis. A change in the value of the resistors changes the frequency of an internal digital pulse. The frequency of the pulses are computed by the formula $T = 10 \times R + 24.2$, where R is the value of the resistance in KΩ and T is the time of a pulse, in μs. The value of the resistors is 100KΩ; thus, the maximum time of the pulse is 1.024 μs and the minimum time of each pulse is 24.2 μs.

To obtain the same result with the VR joystick as with a standard joystick, we use digitally controlled potentiometers (XDCP), with a value of 100 kΩ (X9C104 made by Xicor [20]. The device consists of a resistor array, wiper switches, a control section, and non-volatile memory. The wiper position is controlled by a three-wire interface. The potentiometer is implemented by a resistor array including 99 resistive elements and a wiper-switching network. Between each element and at either end are tap points accessible to the wiper terminal. The position of the wiper element is controlled by the CS, U/D, and INC inputs. The position of the wiper can be stored in non-volatile memory and then be recalled upon a subsequent power-up operation.

3. Experimental results

All measurement results exemplified in the subsequent figures have been acquired using an oscilloscope (type Fluke PM3380). The screen has been read with the service program FlukeView CombiScope version 2.0 that comes with the scope.

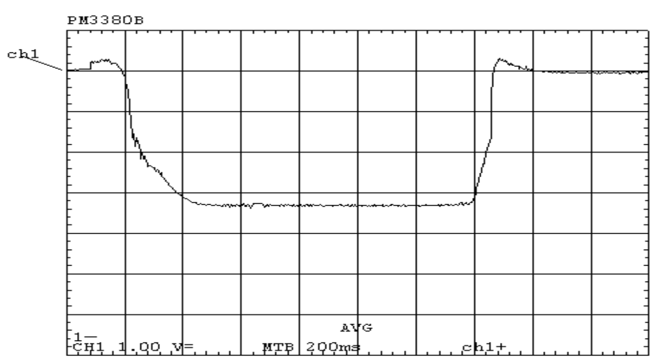


Figure 4. Signal produced by the hand movement

For the VR-Joystick mode, we illustrate in Figure 4 the signal obtained at the output of the circuitry when the hand moves close to a transducer (the bigger one at the base of the printed circuit in Figure 1 (a)). The starting point of the movement is at 30 cm above the surface of the transducer at almost the maximum range of the sensing region. The end point is 5 cm above the transducer. The signal presented here is not amplified; the only pre-processing is made with a passive RC circuit after the rectifier circuit, with the corner frequency 91.82 kHz (figure 1 (b)). We tested the same transducer in tremor signal acquisition and the result is presented in Figure 5.

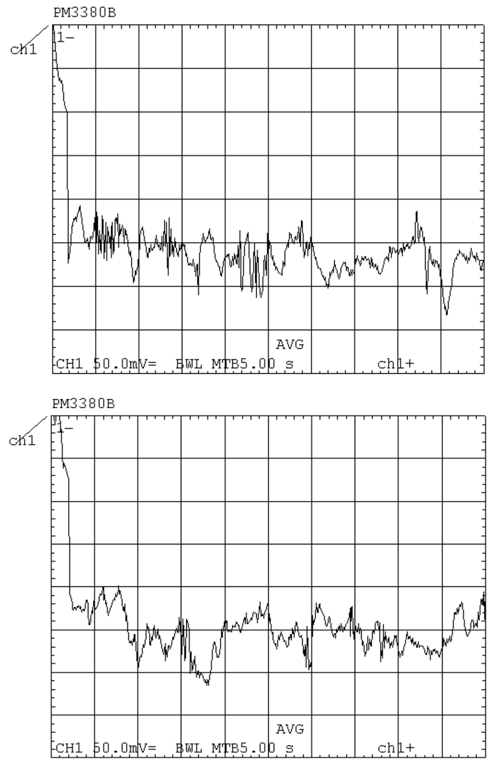


Figure 5. Two examples of tremor signals

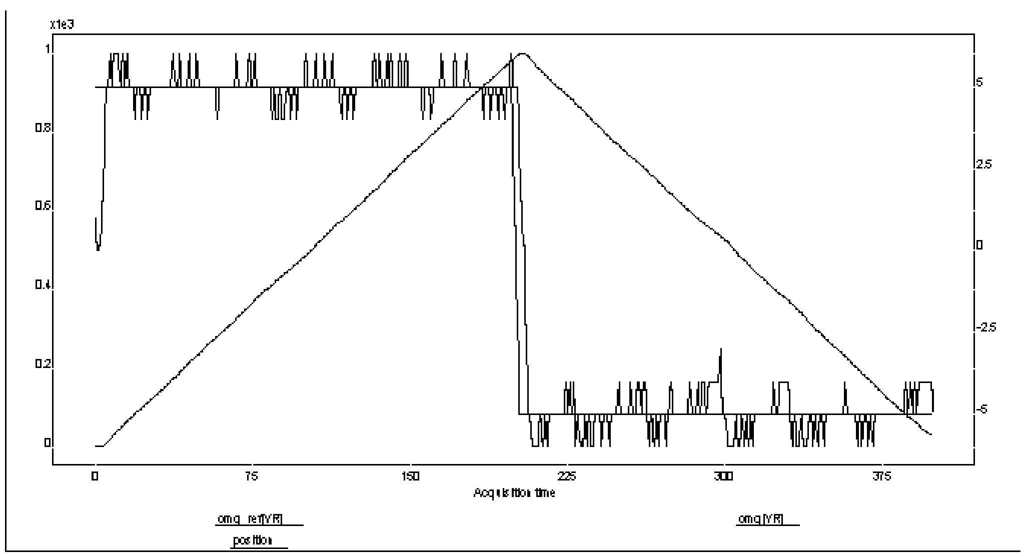


Figure 6. Graphic of motor speed reference, motor speed and position, at 3 Hz cycles

For the tremor measurements, the performance of the sensors is not critical as far as the sensor is low weight (if it is in contact with the hand), or has non-contact measurement capabilities, to avid loading of the hand. Our sensing elements satisfy the last requirement. If we want to perform a non-linear analysis, low noise, high sensitivity, and almost linear sensors are required. This transducer is a very sensitive one; it can sense objects about one tenth of the sensor dimension. For testing the linearity of the transducer, we performed dynamic and static measurements. The sensor used in these measurements was realized on a copper plated board and the sensor element itself had the dimension 7,5 cm × 22 cm.

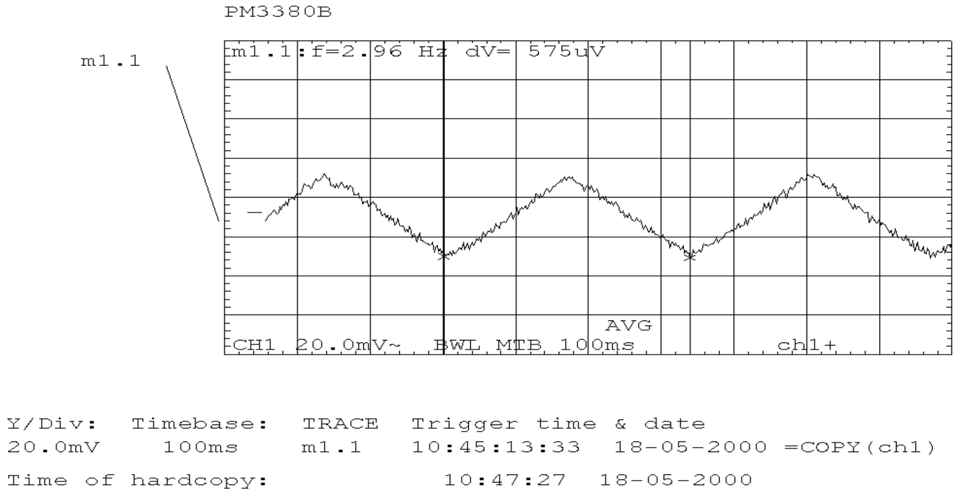


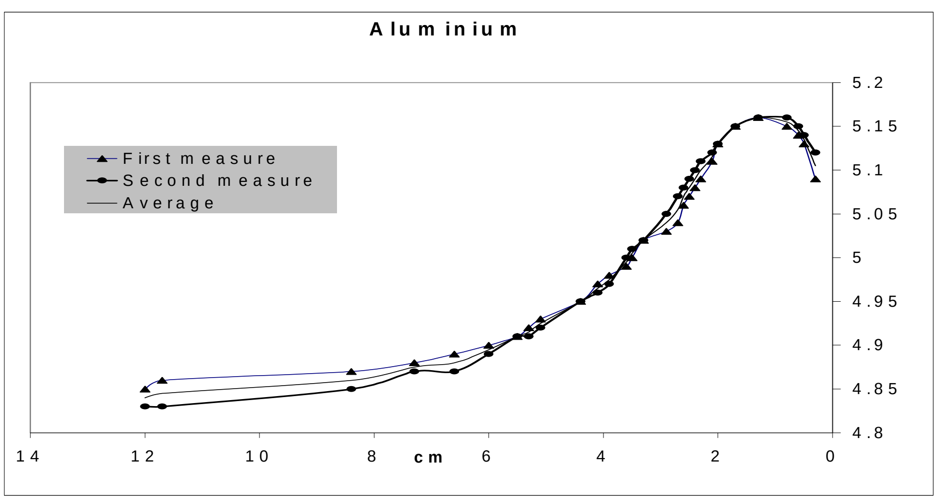
Figure 7. Sensor output for a triangular movement, time-base 100ms, amplitude 20 mV

For dynamic measurements, the object sensed by the sensor is moved on the vertical direction over the sensor and the object is held in position with a support to which an electrical brushless motor (Pittman 3441) has been connected. A TMS320F240 DSP-controller was driving the motor. The control kernel implements the DC motor control mode that contains two PI current and speed controllers.

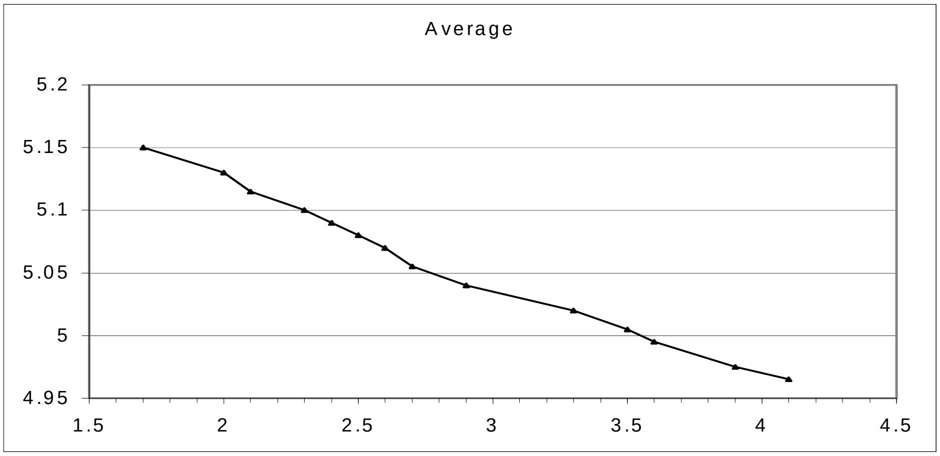
We prescribe a motor speed reference like in figure 6 (ideal rectangular wave), 5 rot/sec in one direction and 5 rot/sec in opposite direction, at a 3 Hz frequency. In the same figure are presented the motor speed (estimated from position variation - the noisy rectangular wave) and the motor position measured on a point on the shaft (triangular wave).

The linearity of the sensors was estimated by using a rectangular waveform of the speed used to control the motor. In figure 7 is illustrated the response of the sensor together with the driving circuit, for the mechanical input presented in Figure 6.

For all the measurements, the sensed object has had the same dimension 6.25 cm $\times$ 6.25 cm. In the static testing for linearity, the sensing elements are made of different materials and are moved on the vertical direction over the sensor. The distance from the object to the sensors has been determined using a rule. The object is held in position with a support.

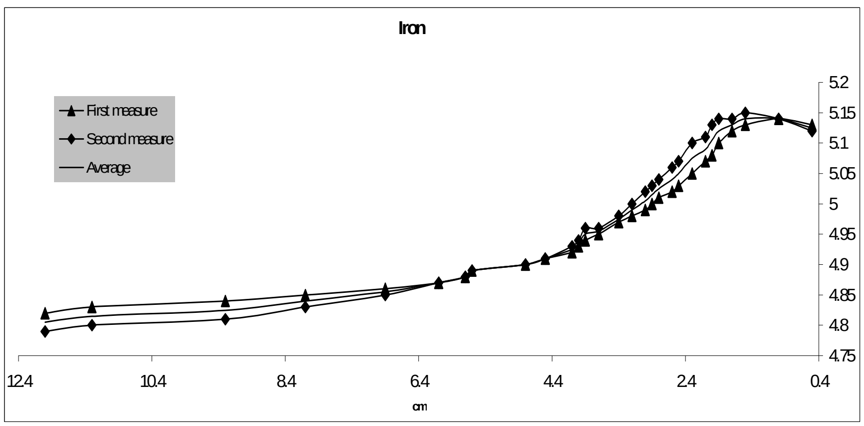


(a)

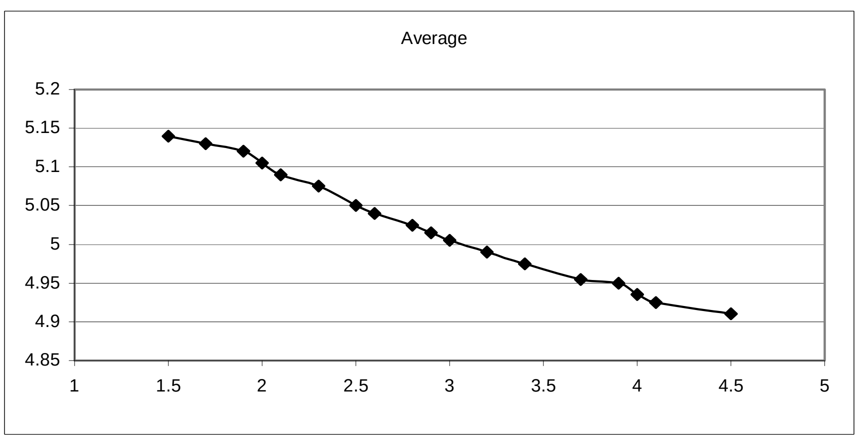


(b)

Figure 8. (a) Static measurements with an aluminium plaque as sensed object (complete curve, including non-linear region); (b) The quasi linear region



(a)



(b)

Figure 9. (a) Static measurements with an iron plaque as sensed object (complete curve, including non-linear region) (b) The quasi linear region.

Figure 8 (a) represents the two measurements and their average, for the aluminum plaque, in the static case and for displacements up to 12 cm. The corresponding quasi-linear segment of the sensing characteristic is show in the same figure, (b). Similar measurements for a sensed iron object are show in figure 9 (a) and (b).

The sensor has also been tested in a medical VR application. Namely, we applied the sensor to detect, without contact, the respiration of a subject. The respiration signal has been detected with a sensing element similar to that presented in figure 1, the only difference being that we use a single transducer element. The sensing element is placed on the back support of a chair.

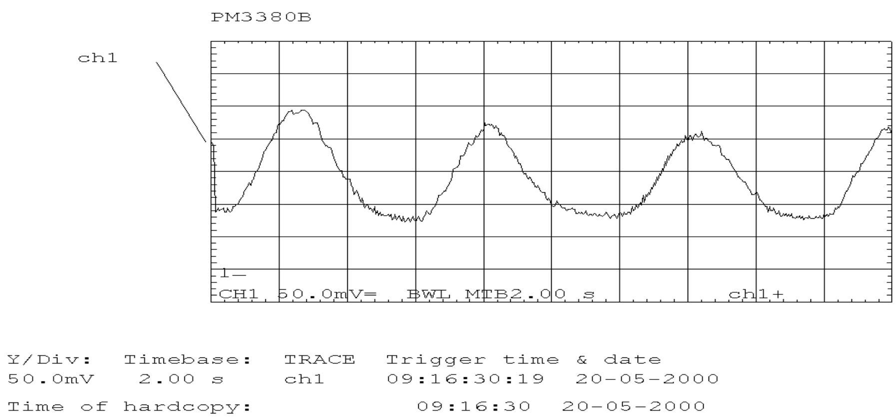


Figure 10. Normal respiration

The measurement results are exemplified in figure 10 and figure 11.

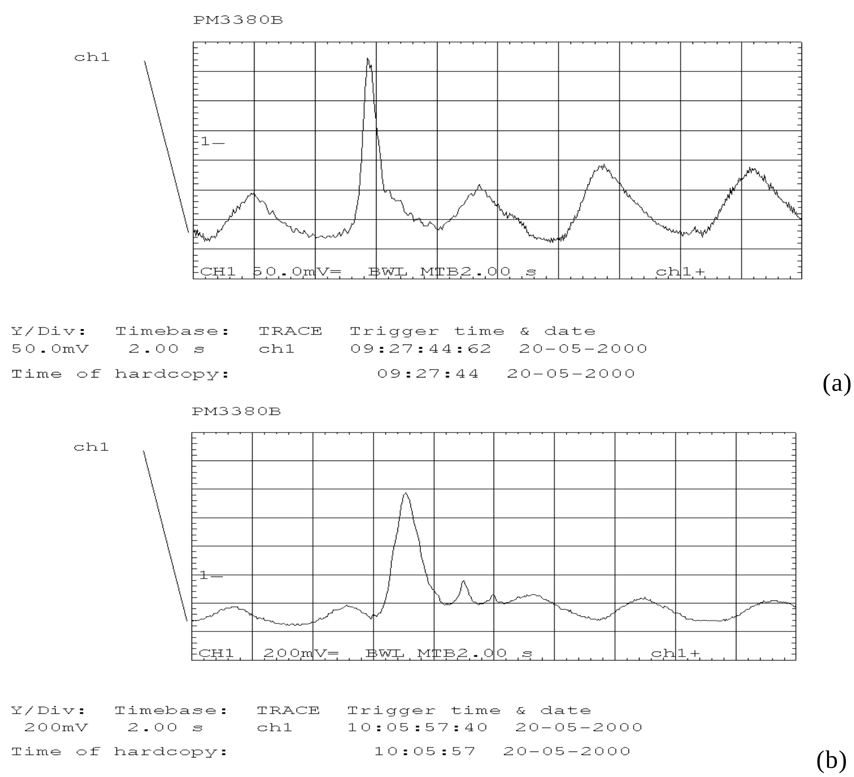


Figure 11. (a) Signal corresponding to respiration plus coughing (the higher peak) (b) Signal obtained during hand movement.

4. Conclusions

The presented sensors and joystick are well suited for applications in both Virtual Reality and medicine. The main feature is that the presented joystick is compatible with a standard one and it can be used without a special board to interface with the computer, moreover without any special software module. The only requirement for the use is a Sound Blaster card with a joystick port. The sensor is cheaper and definitely more reliable than a conventional (electro-mechanical) one. Moreover, its capabilities are higher and the sensor does not require physical contact.

The new interface has several advantages. In the first place, there is the possibility to use it in a variety of applications as it has an excellent sensitivity and bandwidth appropriate for the acquisition of respiratory, movements and tremor signals. In the second place, the system to acquire the signal is based on a non-invasive sensor and the interface between the acquisition system and a personal computer is a standard, cheap one.

Note: A summary of this paper was presented on ECIT'2000 conference [21], [22].

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