A New Type of Non-Contact 3D Multimodal Interface to Track and Acquire Hand Position and Tremor Signal

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Abstract: In this paper I present a new type of multimodal interface (a virtual joystick) that is able to sense and track a 3D-hand movement and, simultaneously, to acquire a reliable hand tremor signal. The acquired hand tremor signal can be used to make correlation between the task executed in the virtual environment and the psychological state of the user. One of the main advantage of the 3D-sensing device is the possibility to track the position of the user hand in the 3D space without any physical contact with the hand. Moreover, the device interfaces with a personal computer (PC) through a standard joystick port and sends the acquired tremor signals directly through the serial port and does not require any expense custom hardware.

Keywords: ***tremor signal, sensor, multimodal interface, DSP, virtual reality***

1. Introduction

The Virtual Reality is characterised by the integration of three concepts: **Immersion**, **Interaction** and **Imagination** [2] that generate a large class of techniques and technologies used to achieve these goals. One of the concepts presented above is **Interaction**. At these moment common input devices – like mouse, keyboards – or the specific ones from different applications – such as standard joystick (computer games) or graphical table (computer aided design) –, cannot provide the sensation of immersion and interaction within complex 3D virtual world. This traditional data input devices have a limited range of the amount of data they can input at a given time; that is because they are limited to one, two or three degrees of freedom. From this reasons new class of input devices with improved human-computer interaction capability are needed.

Among the input devices, the hand-tracking technologies using glove as input devices are the widely used devices in Virtual Reality environments.

Starting with the first large recognised device for measuring hand positions, that was developed by Dr G. Grimes at AT&T Bell Labs [9], the class of the hand-tracking systems knows a large development. This first device had finger flex sensors, tactile sensors at the fingertips, orientation sensing and wrist-positioning sensors. The orientation of the hand was tracked by a video camera. The positions of the sensors were changeable. This glove was created for "alpha-numeric" characters communication by examining hand positions like an alternative tools to keyboards, but it also proved to be effective as a tool for allowing non-vocal users to "finger-spell" using such a system.

The available technologies used and employed to track hand and finger movements related with glove input devices are based on: optic fibre flex (DataGlove [2], 5DT Data Glove [8], Space Glove, Z-Glove), light-tube flex (Sayre Glove), Hall effect (Dextrous HandMaster [2]), piezoresistive bend-sensing technology (Power Glove [2], CyberGlove [2], [14], GLAD-IN-ART glove), electro-myographic registration signals sensor (Cyberfinger glove), pressure sensors (TouchGlove [12]) and small switches (PINCH Gloves [6]).

Other hand input devices used and related with application into Virtual Reality are 3-D mouses (like SpaceMouse, which has become the most popular 3D-graphics input device in Europe with more than 12000 instalations up to 1997 [11]) or more sophisticated devices like PHANTOM [21] or Rutgers Master glove that integrate haptic feedback.

Various applications of glove, 3-D mouse or haptic interface technologies include: sign-languages [9]; speech synthesiser for vocally impaired [7], [10]; music; remote-controlled operations (teleoperation) in space [11] and hostile environments; surgical simulations; rehabilitation [13] or telerehabilitation [3]; movement analysis [10]; training of medical staff [1]; etc. to name only few of them.

All of Virtual Reality hand input devices have some disadvantages: dependence on the principle involved in the device function or other drawbacks correlated with the Virtual Reality practical application. Because of these, for a particular Virtual Reality application, the input device must be chosen carefully. For such a system [10] that wants to evaluate hand impairment – in order to determine the presence of pain and any loss of sensation and/or range of motion and strength – the input devices was a DataGlove. This configuration of the system, with a DataGlove like an input device, reveals several problems. The DataGlove devices showed hysteresis, and, in this mode, made almost impossible to obtain repeated measurements of the same parameter, in the same condition and, more, it made difficult to determine the accuracy of the measurements. For accurate measurements it is important to have a perfect fit of the hand into the glove (this problem appears for almost all glove devices) because different placements of the sensitive area will determine incorrect measurements. This aim is very difficult to achieve because of the variability – in shape and size – of the hand among population. The presence of three sizes (small, medium and large) of some input glove do not solves the problem. Moreover, the use of glove excludes the population with anatomical hand deformity. One of the conclusion drown from this evaluation system, it was to build an improved version of the input devices in order to get better results [10].

When the realism of the feedback force sensation is desired, the standard Phantom devices reach its limits [18] (for example, in case of the surgical tools simulation). This happens because this haptic device is point-based orientated. To avoid this problem the Laboratory for Human and Machine Haptics (MIT's laboratory) developed a system and algorithms to control two Phantom devices and, in this mode, the contact with the virtual environment of virtual instrument became a line.

On the other hand, all hand movements devices presented above, generally involve some forms of direct contact with the hand, thus being obtrusive. To eliminate these problems, new devices must be developed. All actual devices are mainly projected to supervise hand or/and finger movements. If we expect more functions from them (like physiological signals – tremor signals – or hand motor assessment, etc), this could be impossible because these devices were not designed, from the beginning, with these incorporated functions.

This paper proposes a new type and configuration for the hardware and the software used to **track, without contact, the hand position** in the **3D space** and to **acquire a reliable hand tremor signal** that can be used to asses the emotional and psychological state of the user.

This communication have the following parts: the section 2 presents the method of tracking the hand position and the operating principle for the sensors; the next two parts of the paper present the hardware and the software implementations, followed by practical results and the last section concludes this paper.

2. Method and operating principle

A group of three sensing elements (**figure 1**) is used to track the hand position in a 3D input space. In the moment when the hand is above one of the sensors, the output of the corresponding driver circuit has a high value. The distance between the sensor and the hand, the shape and the hand dimensions, the other objects presented in the active area of the sensor – all of them are factors that can influence the magnitude of the output signal of the one of the three output channels. To sense the position and, for example, the swing hand movement, the information from the two paired sensors must be used. In this mode, the difference signal from the couple of sensors evidences the position of the hand.

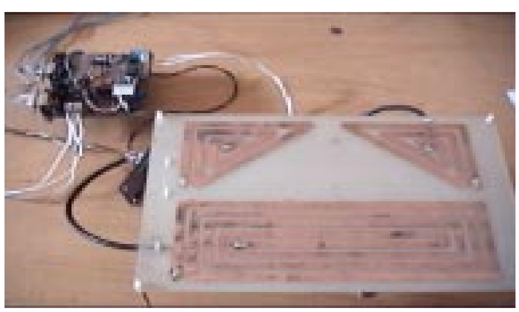


Figure 1. 3D Multimodal Interface (the virtual joystick): the sensors and a part of the electronic processing system

The transducer is a R_E, L_E, C_E parallel circuit. The R_E, L_E, C_E represents the equivalent of parasitic distributed resistance, inductance, and capacitance of the resonant sensor. All sensors generate an external electromagnetic field. The change on its impedance, viewed at the port of the measuring device, is due to the properties of the objects in its close vicinity. This change is due to the variation of the equivalent impedance (either reactive or resistive). For the impedance change to be high enough, the oscillator should excite the transducer with a high frequency signal situated on the linear part of the sensor characteristic (**figure 2(b)**) – the bold part of the characteristic.

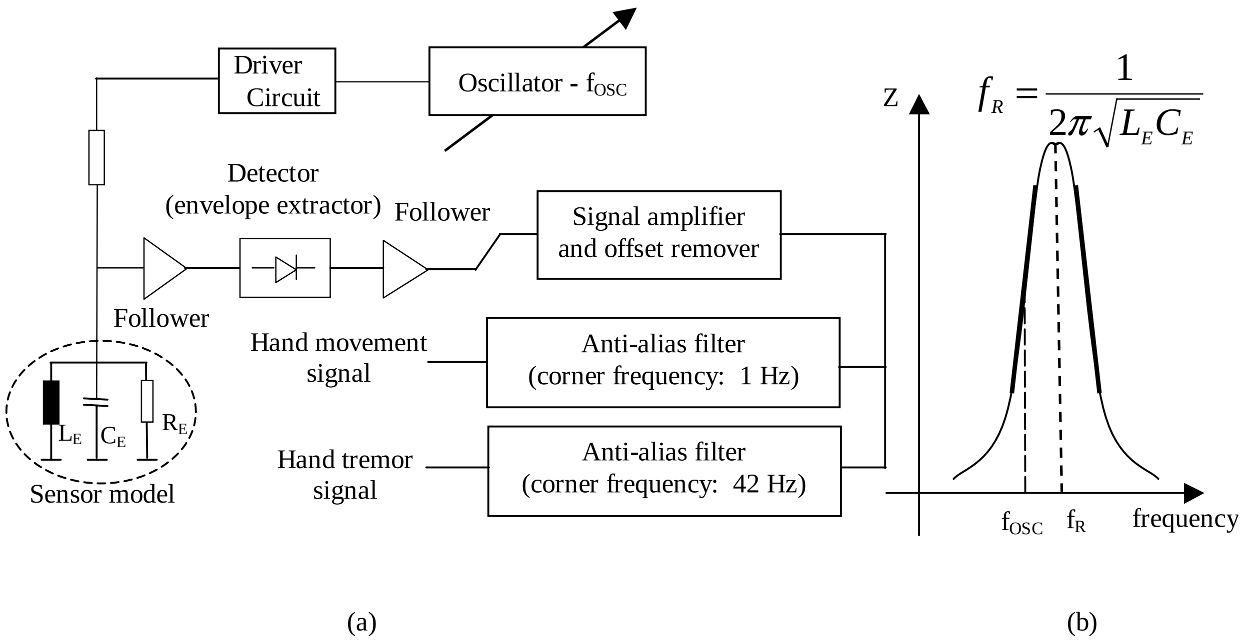


Figure 2. (a) Block scheme of circuitry used to drive and control the sensor **(b)** Sensor characteristic

When the hand starts to close the sensor, the R_E, L_E, C_E components start to change their values, lowering the resonant frequency, f_R (this is relative to the operating frequency, f_{OSC}). The shift away of the resonant frequency determines the changes of the impedance Z of the resonant sensor.

Accordingly to [19], the sensors are composed of planar windings that, in our case, take two basic shapes (**figure 1**). The winding has a relatively large conductor width and a relatively small spacing between successive turns (**figure 1**) in order to achieve a suitably high stray capacitance between the turns. As result, a large overall capacitance for this resonant sensor is achieved. Moreover, the winding is shaped to provide a relatively uniform electric and magnetic field in a sensing zone. The operation of the sensor is presented completely in [19].

Because the reasons that the resonant sensor system is employed in the object distance-sensing mode all the sensors must work in the linear part of their characteristics. Especially, because from the bottom sensor is extracted the tremor signals (the bigger one from the **figure 1**) at least this one must to work in the linear part of the sensor characteristic. The chaotic and random components of the tremor signal are very sensitive to the non-linear features of the system and, from these reasons, the system must be a linear one.

The picture of the multimodal virtual joystick sensor is presented in **figure 1;** the general scheme of the circuitry used to drive the sensor, situated in the bottom position, is shown in **figure 2 (a)**. For the other two movement sensors (the two upper and smaller sensors, with a triangular shape) the circuit is the same but the anti-alias filter path for tremor signal is missing.

The resonant sensor and the resistor (**figure 2 (a)**) form together a voltage divider circuit that generates, at their junction, a signal that is directly representative for the position of the hand in the proximity of the resonant sensor. The driving circuit is used to command and supply the sensor with a fixed amplitude sinusoidal wave of signal and to isolate the oscillator from the change of the sensor impedance. In this mode, its oscillator frequency does not change the value. The oscillator can be tuned around 16 MHz. The driving circuit is made with a class D amplifier. To obtain good high Q factors for the resonant sensors and a good sensitivity, the voltage follower circuits connected parallel with the sensor use the current feedback operational amplifiers LT 1229 that have

100MHz bandwidth, high input impedance of 25 MΩ and low capacitance of 3 pF. The operational amplifier must have a low capacitance; otherwise, the sensitivity of the sensor to dielectric objects starts to decrease. The detector extracts an average envelope voltage from the input signal and it is built with Schottky diodes. The resulted signal represents the hand position and the tremor signal with the hand movement signal. The filters are low-pass and are used to separate the signals (more details in the next section). The electrical implementation of the block described until now can be fount in [4].

3. Hardware

In **figure 3** is presented two views of the practical implementation of the schematics shown in **figure 4**. The "heart" of the entire multimodal virtual joystick interface is the digital signal processor (**DSP**) TMS320F240 produced by Texas Instruments™. Basically, in the system, it:

- supplies the clock signal for three digital filters; in this mode, it can, dynamically modify the corner frequency of the low-pass filter and supply the converter with a movement signal, more or less reached in spectral components;
- acquires (in the same time, but at different rates, on different processing paths like in **figure 2**) hand movements and tremor signals;
- derives, from the information supplied by the group of the three transducers, the exact hand movement and position in the 3D space;
- commands three digital potentiometers;
- transmits, in serial mode, the tremor signal acquired and locally stored.

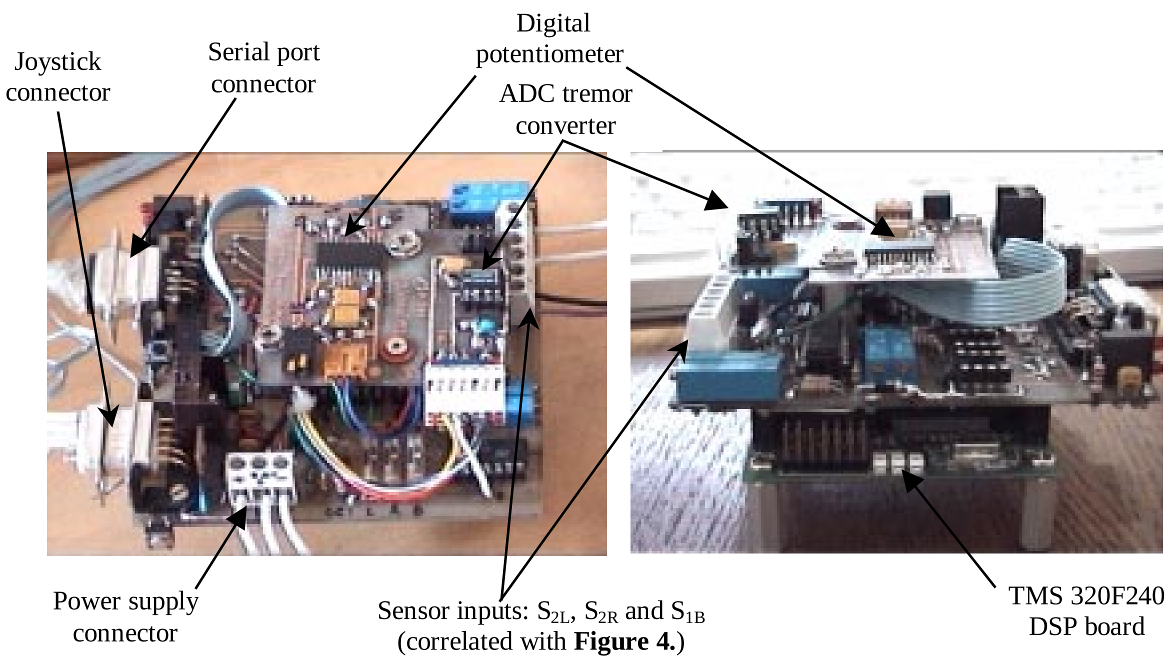


Figure 3. Part of the practical implementation of the multimodal virtual joystick

Because from the starting point of the design, one of the **main goal was to get a "crystal-clear" tremor** signal, special precautions must be taken. In case of the tremor signal, the noise (quantization, power supply hum, sensor driver oscillator signal, etc), the non-linear characteristic of the pre-processing system [20] and the artefacts can destroy the very noise sensitive non-linear information and can lead to unreliable results.

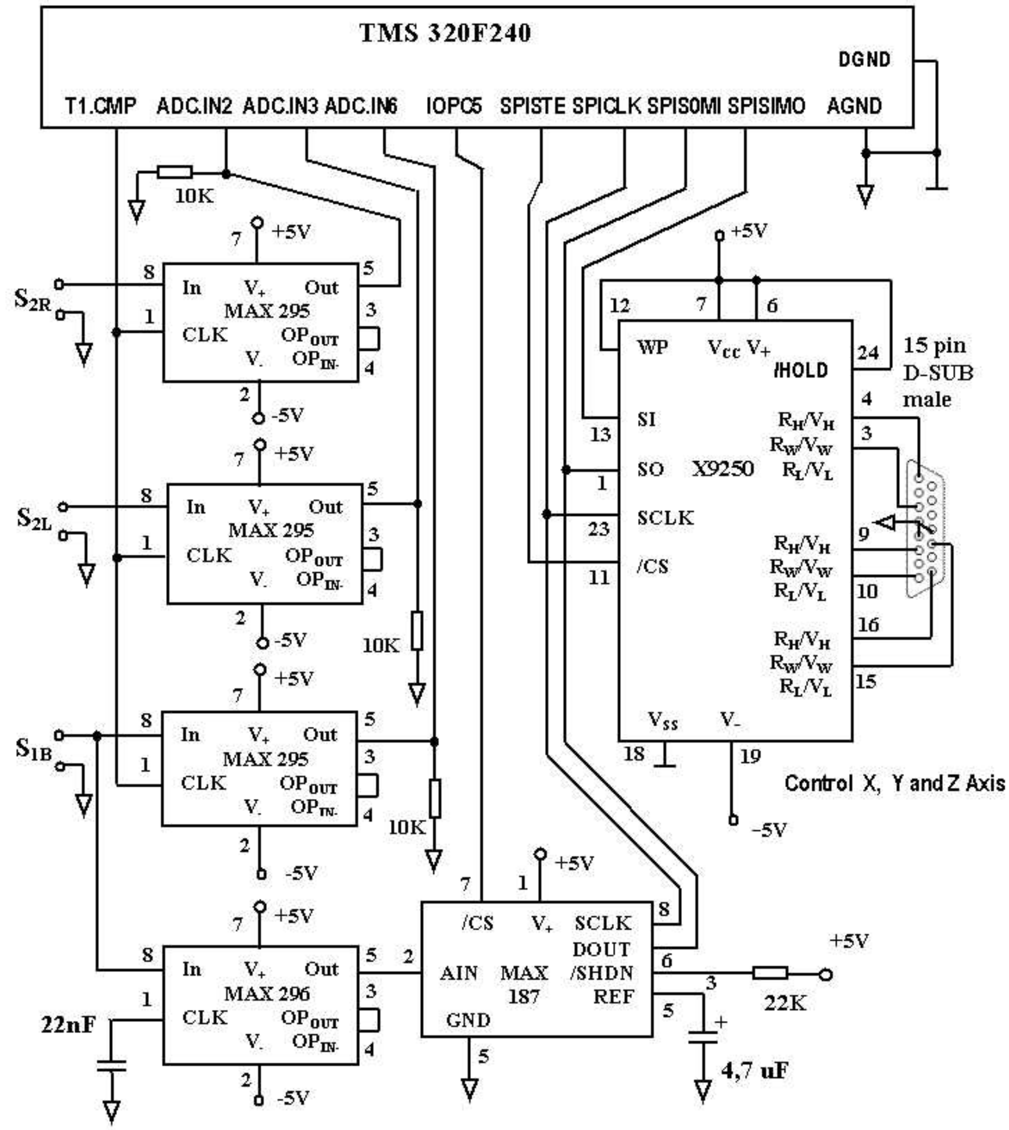


Figure 4. Schematics for anti-aliasing filter (for tremor and movement path of the signals), DSP, tremor acquisition converter and digitally-controlled potentiometers

In order to get a "crystal-clear" tremor signal I used, in the tremor signal acquisition path, a linear phase response filter. Since the *MAX 296* [16] has, in the pass-band, a linear phase response (because is a Bessel filter), all frequency components are equally delayed, preserving very well the input signal frequency characteristics. The cut-off frequency for the Bessel filter was chosen in order to satisfy a number of constrains:

- *Physiological characteristics of the tremor signal*. For example, if we consider a pathologic case, Minor disease [23], the essential tremor have the "main frequency" (the highest peak in the Fourier spectrum) in the range 7-11 Hz. The bandwidth of the tremor signal is difficult to establish, but if we want to make chaotic analyses this must be larger. Generally, it is considering larger then 10-40 Hz [20];
- *To satisfy the Shannon Theorem* – that because it is used like an anti-alias filter;
- *To remove the power supply hum* (50/60 Hz and 100/120 Hz);

- *To remove the noise frequencies*, which, for example, in medical applications are greater than 150 – 200 Hz.

The cut-off frequency was set at 42 Hz. The capacitance (22nF from **Figure 4**) at the CLK pine and the stray capacitance, at the same pin, determine the internal clock oscillator frequency of 2.1 KHz. The rate of 50:1 between clock frequency and the corner frequency of the Bessel low pass filter determine the above frequency value.

The tremor signal is acquired using the MAX187 [15], SPI™ serial converter, 12-bits analogue to digital converters. In a previous research [5], the second analogue to digital converter (**ADC**) from the DSP was used. The disadvantages of this solution were generated by the fact that the internal converter of the DSP is on 10-bits; as a result, the sampling and quantization noise generate unreliable results and, further, the possible linear and non-linear analysis are impossible. At that moment of time the solution used to solve that problem was to compensate this externally by the amplification of the signal. The drawback of this solution was generated by the fact that only between the two limits (spatial limits on the normal direction on the sensor) of the dynamic range of the movement was possible to record the tremor signal. These spatial limits were very close and represented approximately only 20% of the whole hand vertical movement range sensed by the sensor. If the hand was above the upper vertical spatial limit, the signal – received by the internal tremor DSP converter – where above 5V threshold analogue input limit (the internal ADC of DSP can convert signals only for dynamic range of input between 0V and 5V). In this mode the digital value gated do not more represent the reality. If the hand was under the lower spatial limit the signal received were under 0V analogue input limit and we had the same situation. From the reasons presented above, in the new multimodal virtual reality device presented in this paper, an external ADC on 12-bits is, now, used to acquire the tremor signal. The sampling frequency for tremor signal is chosen to be 120 Hz.

The information about the movements of the hand, supplied by the three channels corresponding to the three sensors, is acquired with the first ADC internal from DSP. Before acquiring the signals, three anti-aliasing filters realised with the Max 295 circuit (**figure 4**) (8th-order, low-pass, switched-capacitors filter) was used. The Max 295 [16] is a Butterworth filter that provides maximally flat band response. The 8 poles provide 48dB attenuation per octave.

The TMS320F240 circuit symmetrically drives the CLK pin of MAX295, on 50% duty cycle at 50 Hz rate; in this mode, the low-pass corner frequency becomes 1 Hz. The timer 1 in the DSP generates this clock signal. From the starting point of the design the possibility to change the corner frequency of the low-pass filter, accordingly with the sampling rate of hand movement/position, was considered for further developments (the case of acquiring a more reach spectral information about the hand movement was considered). To acquire the movement signal, we used one 10-bit ADCs string/capacitors converter that is available on TMS320C240. From the eight analogue inputs that are provided for each ADC unit I used only three of them. For the three input channels, the lines ADCIN.2, ADCIN.3 and ADCIN.6 are connected and sampled at a time interval of 300 ms. These samples are used by the DSP to compute the hand position in the input 3D space.

To reduce the cost of the multimodal virtual joystick, one of the starting goals was to interconnect it with the personal computer (**PC**) using only the standard ports. For hand movement signal, we used joystick port that usually is not integrated in the motherboard of the PC, being implemented in multi I/O interfaces or soundboards; for tremor signal is used the serial port. The joystick connector enables the control of two joysticks at the same time or of only one joystick – if this device contains the third axis. Inside the standard joystick, the stick is attached at two 100 KΩ potentiometers. The resistors change their value according to the change in the position of the stick along the axis. Knowing this information, we change the value of the digitally controlled potentiometer X9250 [22] accordingly with the movements, generating controlling instruction conforming to the requirement of the communication SPI™ bus of this circuit. Previously, the right choose of the /CS select pin must to be made (at this time, on the SPI™ bus two devices are connected).

4. Software

To drive the virtual joystick and, respectively, to display the hand position I used two software components. The first one is the software that runs inside the DSP and the second one is the software application on the PC.

The software module used to drive the DSP is written in C and a small, critical part of it (which requires a faster execution), is written in the assembler language; both software programming languages are dedicated for TMS320F240 processor. In the first part of the DSP software all the initialisations are made: for all the three timers, for the internal ADC converter, the SPI™ port, the interrupts and internal variables etc. The DSP runs in an internal loop and waits a command from the PC in order to start the acquisition of the tremor signal. In the same time, the second DSP timer generates interruptions. In the interrupt service routine (**ISR**) that serves the second timer, the movement signal is acquired from all sensors and, from these samples, the real position in the 3D input space is computed following the next relations:

$$X_{Pos} = V_{Out\,L} - V_{Out\,R} \qquad Y_{Pos} = \frac{(V_{Out\,L} - V_{Out\,B}) + (V_{Out\,R} - V_{Out\,B})}{2} \qquad Z_{Pos} = \frac{V_{Out\,L} + V_{Out\,R} + V_{Out\,B}}{3}$$

where: $V_{Out\,L}$ and $V_{Out\,R}$ represent the samples taken from the output of the driver circuits for the sensors (left and right) of the triangular form; $V_{Out\,B}$ represents the information supplied by the bigger, bottom sensor.

When the multimodal virtual joystick receives a specific command send by the PC, it starts to acquire 1024 samples of the tremor signals at a rate of 120 Hz and stores them locally. When the process is finished the multimodal virtual joystick is capable to send the information, in the serial mode at a rate of 38.400 bps (bits per seconds), to the PC. All the time when the tremor signal is acquired, the virtual joystick part of the system (hand tracking part) is runing without interference.

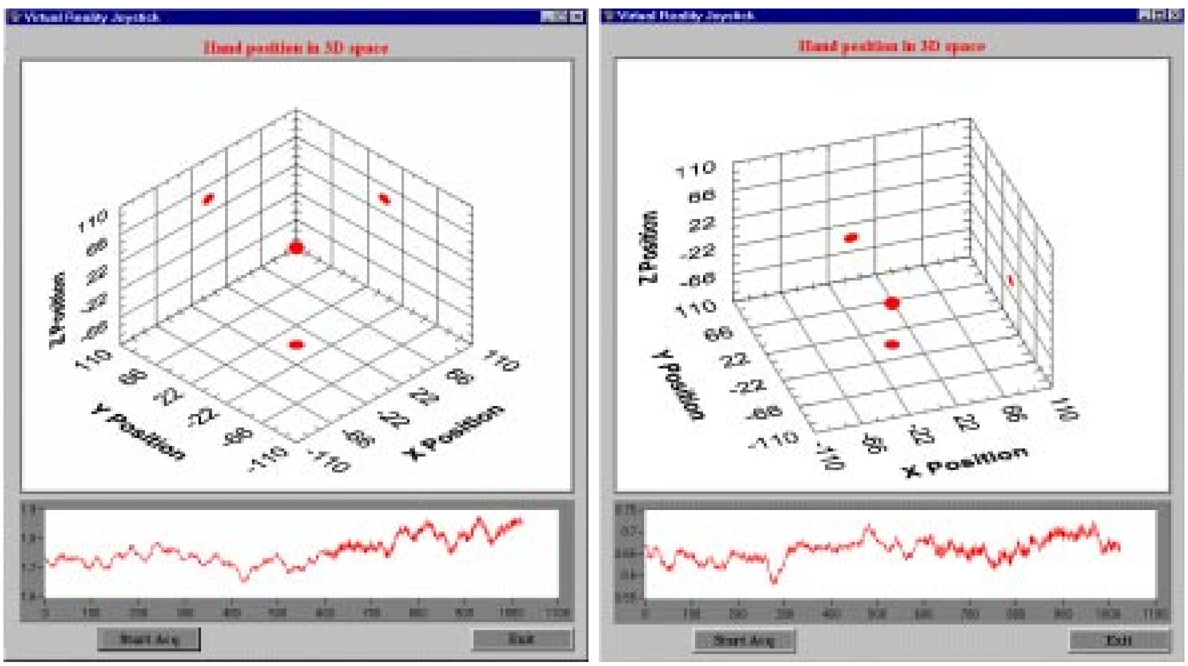


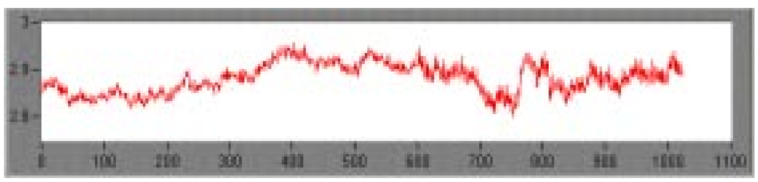
Figure 5. Two snap shot with the main window of the PC software program, the red dot representing the hand sensed by the 3D virtual joystick

To develop the software from PC, I used Microsoft™ Visual C++ 6.0 programming language together with Measurement Studio ComponentWorks++™ library that extends Visual C++ and brings measurements, automation and graphics for virtual instruments into Microsoft™ environment. The Joystick port is interrogated through SDK Microsoft™ library. The software shows, in the upper part of the main window, the position of the hand in 3D input space and the projection of this point on the all three planes that define de virtual space correlated with the virtual joystick multimodal sensor orientation. The active workspace, where the position of the hand can be tracked, has the dimension of 40 x 48 x 20 cm. The viewpoint of the 3D virtual space can be modified accordingly to the user wishes, like in **figure 5**; there, two snap shots are presented from two different points of view.

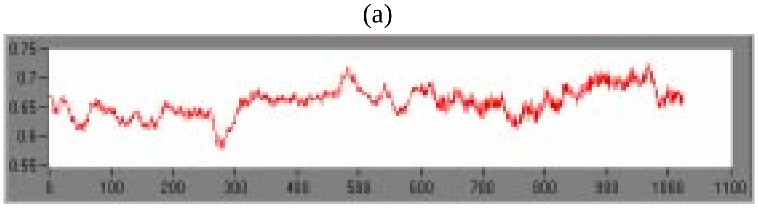
In the bottom part of the main window the tremor signal acquired by the virtual interface is presented. The time to transfer the buffer of tremor data signal between the virtual joystick and the PC is almost 7.15 seconds. This time is reached if we consider the next information: the buffer has 1024 samples of 2 bytes; the speed of transfer is 38400 bps and, for sending a byte, it is necessary 11 bits. This is with 3 bits more than the eight bits carriers of information (these bits are: start, stop and parity). Because the time of the transfer is too long, a new thread of the program is created. This thread carries out only the transfer task. In this mode, the user do not wait almost seven seconds until the position of the hand in the virtual space will be updated again.

5. Practical results

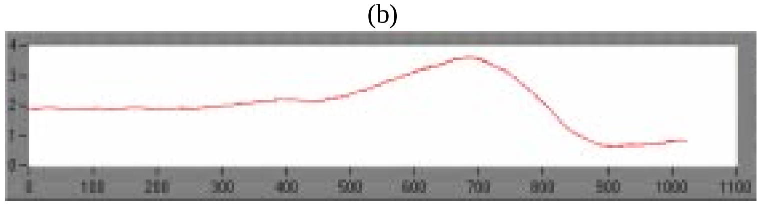
In **figure 6 s**ome of the resulting tremor signals, acquired by the multimodal virtual joystick, are presented. In the first two acquisitions, the users were seated and asked to keep their arms in a fixed position, making an angle of 30° with the horizontal plane. The hands were above the sensor, parallel with the multimodal virtual joystick sensor surface and with the spread fingers. In one recording, **Figure 6 (a),** the hand was above the sensor at 15 cm and in the **Figure 6 (b)** at the 6 cm. The information about different high positions of the hand can be observed from graphical representation of the tremor signal. This information is contained in dynamic range of the values acquired; for example in **figure 6 (a)** the dynamic range starts with 2.8V and ends at 2.95V; in **figure 6 (b) it** starts with 0.555V and ends at 0.725V.



(a)



(b)



(c)

Figure 6. Examples of tremor signals

In **Figure 6(a) and 6(b),** in the second part of the acquisition, the tremor signals became more “noisy”. The same results can be viewed in **figure 5.** This happens because at the end part of the acquisition, the fatigue was installed. We must to keep in mind the fact that the user was asked to stay with the hand in the same frozen position a time around 8.5 seconds.

In **figure 6 (c)** the subject is asked to start to wave the hand up and down starting from a middle position of 10 cm, keeping all the time the hand parallel with the virtual joystick surface. In the resulting signal acquisition we can see the presence of the tremor, which is of lower amplitude comparing with the hand movement signals. In this case, if we want to obtain only the tremor signal, we must to eliminate the movement signal that represents the tendency component. This will be done in the future. Basically, the idea is to register (from the movement channel, where the tremor is filtered out), for example, from twenty to twenty tremor samples only one sample of movement and to interpolate these points and, at the end, to eliminate this component from the tremor signal.

5. Conclusions

If we analyse the input devices used, throughout the world, in research, entertainment or other fields related with virtual reality, it can be found, at least, three limitations [17] that are against a large emerging of this devices into every day applications:

- costs,
- lack of reference standards and,
- non-interoperability of the systems.

With this multimodal virtual reality device I tried to eliminate these problems.

The *sensor is cheaper* and the driver circuits – that are compound only of passive components, transistors and operational amplifier – are the same. The core of the virtual joystick (TMS320F240 DSP) is the most expensive component (around 17$). In conclusion, for all components and parts someone must to pay no more than 100$. If we put the work, the printed circuit board and other parts (connectors, wire, etc) and make a comparison with other hand tracking devices that are sold at the price starting with 500$ up to 25.000$ or more, the difference can be easily found.

One of the main features is that this multimodal virtual joystick *can be connected to a computer without a special board to interface*. The movement is transmitted through joystick port and the tremor signal through serial port. In this connecting mode of the multimodal virtual joystick, *all the standards that exist at the actual moment are respected and used* and the *possibility to use the device on different platform* like Windows™, Linux™ or Solaris™ will be without problems.

The connecting mode of the multimodal virtual input device presented above, solves another problem: it is *no need to develop special driver* for this device any more; for example, the standard functions provided by Microsoft™ (when the class of Windows™ operating systems is used) that work with joystick and serial port can be used. The only requirements for the use of the multimodal input device are a Sound Blaster card with a joystick port and a free serial port.

Another advantage is conferring by the fact that *the tremor signal, acquired with the sensor, is a very reliable one, without any compromise in hand tracking mechanism.* This is achieved by using a set of techniques (soft and hard) and technology dedicated to this goal:

- *the bandwidth of the transducer is appropriate for the acquisition of the tremor signal*; basically, this is due to the high frequency operation of the sensors;
- *the mode of setting the work of the sensor in the linearity part of the characteristic*;
- *the processing techniques involved in the tremor path of the signal*;
- *the precaution used to acquire the tremor signal*;
- *the software solution used in subroutine implied in the data transfer* between the multimodal virtual joystick and the PC.

Besides these, the multimodal virtual joystick is *a non-invasive device* used to acquired hand position/movement and tremor signal *without physical contact with the hand.*

As conclusion of this paper, the presented multimodal virtual joystick is well suited for applications in virtual reality, human computer interface and medicine.

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Switzerland and H.N. Teodorescu, that had the idea and suggested the use of the sensor from the patent [19] in the direction of virtual joystick future research. The sensor is protected by a patent [19] and any attempt to use the sensor without written permission of the Prof. Horia-Nicolai Teodorescu and the owners of the patents is forbidden. This paper does not create any rights for use of the sensor described herein and in [19] by any person or institution.

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