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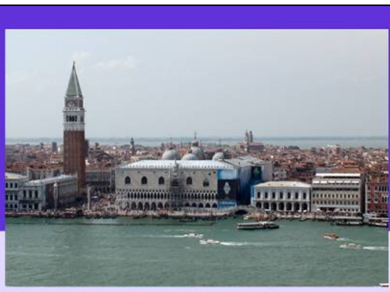

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MEMS Accelerometers Sensors: an Application in Virtual Reality

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Abstract: The measurement of a particular human body member position is extremely important in many applications. The human behavior understanding typically involves the body posture analysis or estimation, as well as the generated corresponding gestures. This behavior characterization allows analyzing, interpreting, and animating human actions and therefore enables us the use of experimental methodologies. Using the virtual reality devices to facilitate people's lives, they can help to train and improve the actions of an Olympic athlete, for example and imitation of human actions by robotic systems. The systems development to monitor human body members' movements is a growing interesting area, both in entertainment and in systems to help physically disabled people, as that developing assistive technology. To contribute to this area, this paper presents the experimental development of an instrumented glove prototype of low cost for the recognition of hand inclination movements, using a *Micro-Electro-Mechanical Systems* (*MEMS*) accelerometer, by virtual reality concepts for demonstration in real time. We present the hardware that was developed, the calibration procedures, the achieved results with their statistical corresponding validation. The results allowed to state that the system is suitable for the inclination measurement in a 2D plan, thus allowing its use in entertainment systems and as an auxiliary device for assistive technology system. *Copyright © 2010 IFSA.*

Keywords: Virtual reality, Accelerometer, MEMS technology, Instrumented glove.

1. Introduction

The position or displacement characterization of a particular human body member in various applications is extremely important. Several methods can be used to measure linear or angular displacement, velocities, and accelerations. In most instrumentation systems, the displacement or acceleration measure is performed directly with a suitable sensor, while the speed is sometimes obtained by integrating the acceleration signal. The velocity and acceleration proper definitions suggest that any suitable quantity should be measured and another one could be determined by integration or differentiation of acquired signal by the experimental scheme [1].

Human body's virtual models are used in many applications that allow human-machine interaction like in certain video games. The motion carried by these models must be as realistic as possible [2]. Therefore, the animation techniques of these virtual models must be flexible to allow interaction with the environment and with other objects or virtual beings in real time. This flexibility can be obtained through specific animation techniques [3-4] or can be directed by physical controllers [5]. The development of human body's models and their corresponding movements attract huge interest from many professionals [6-7]. But there is much work to be done, since existing techniques still need improvement to adapt to the human body, which has a complex geometry, articulated, and covered with deformable tissues such as skin and clothing. The kinematics study and its measurement during the movements' execution is an important requirement in the orthopedic rehabilitation area [8] and in animation systems [9].

The virtual reality systems development currently allows the creation of advanced man-machine interfaces, enabling the creation of a 3D world, in which the user can manipulate and explore objects or environments as if they were real, as if the users were physically in contact with the object or within the environment. Applications for virtual reality include several areas, being used in medicine to study an organ by three-dimensional way and to make surgical interventions simulations. In engineering, for example, there are applications for simulations of building prototypes. Another application is the handling of three-dimensional objects by human gestures. Automatic recognition of human gestures has shown a rapid development in recent years and indicating promising prospects for the segments related to this area.

Considering the foregoing, this paper presents the development of an instrumentation system of low cost, using an accelerometer sensor fixed in a glove, to read human gestures in real time. With the development of a sensor-computer interface, it was possible to acquire the sensor's signals that control the movement of objects in three-dimensional animation in a computer.

2. Accelerometers: a Short Review

Sensors for acceleration (often called accelerometers) provide proportional output to acceleration, vibration or shock. There are accelerometers in different sizes, technologies: especially the piezoelectric, piezoresistive, and capacitive. In recent years, the integrated accelerometers called MEMS (Micro-Electro-Mechanical Systems) are highlighted. Furthermore, there are various encapsulation types, axis measurement, amplitude's different ranges (usually characterized as a gravity function), and of frequency [1].

In the industrial area, it is used in several systems, mainly to monitor vibration in mechanical systems: axis, bearings, and vehicular systems, among others. In health area, the accelerometer can be used, for example, to characterize the human members inclination, occupational vibration and acceleration (an area known as human vibration) [10].

The basic principle of any accelerometer is the acceleration action in a mass to produce force following the famous Newton's Second Law [1, 10]:

$$F = m \times a$$

in which $F\ [N]$ is the force, $m\ [kg]$ is the mass (called inertial mass), and a the acceleration in m/s^2. A strain-gage sensor type can be connected to an inertial mass, with or without cushioning (damping element) or suspension system (called the spring element) to measure the acceleration. The most common accelerometer uses an inertial mass coupled to a piezoelectric transducer. These transducers facilitate the achievement of two-dimensional signals, which respond to a wide frequencies' range. In a simplified form, a generic accelerometer can be modeled mathematically as shown in Fig. 1.

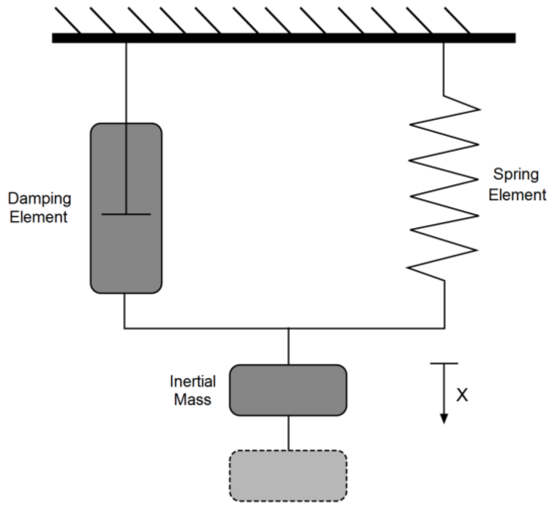

Fig. 1. Model of an accelerometer comprising a seismic mass, a spring element, and a cushioning element.

Any inertial force due to acceleration moves the mass, according to Newton's Second Law, so that the system of Fig. 1 can be modeled mathematically by:

$$\frac{x(s)}{a(s)} = \frac{1}{s^2 + \frac{b}{m} + s\frac{K}{m}}$$

in which s represents the Laplace operator, x, the mass displacement from its rest position, a, the acceleration being measured, b, the cushioning coefficient, m, the mass for the motion, and K, the system spring constant. The system natural frequency, ω_n, (sometimes it is interesting to determine the transfer function from a system, according to the natural frequency and quality factor Q) is given by:

$$\frac{x(s)}{a(s)} = \frac{1}{s^2 + \frac{\omega_n}{Q}s + \omega_n^2}$$

With

$$Q = \frac{\omega_n \times m}{b} = \frac{\sqrt{m \times K}}{b}, \ \omega_n = \sqrt{\frac{K}{m}}$$

whose sensitivity (S) to a not replenished system is given by

$$S = \frac{m}{K}$$

in which K is the spring constant, and m is the seismic mass.

The chosen accelerometer should be appropriate to application, so it should have sensitivity, frequency range, amplitude, and dynamic range suitable. Common accelerometers have a linear range, between, 50,000 m/s^2 to 100,000 m/s^2, while accelerometers suitable for measuring mechanical shock have the linear range ending at 100,000g approximately. The most mechanical systems presents dynamic behavior in 10 Hz to 1 kHz frequency range, but in human vibration the interest range lies between 1 Hz to 300 Hz depending on the segment [1].

Piezoelectric accelerometers: in summary, we can say that piezoelectric transducers transform small amount of mechanical energy into electrical charge. Piezoelectric accelerometers use a mass in direct contact with a piezoelectric element. Piezoelectric materials have high output impedance (small capacitance with high resistance) and therefore, a conditioning circuit called charge amplifier must be used to measure the generated signal. Piezoelectric sensors offer high sensitivity and usually have low cost.

They respond to lower deformation than $1\mu m$ and are adequate to measure variables efforts such as force, pressure, and acceleration. Their small size (can be smaller than $1mm$) and the possibility of devices fabrication with one-way sensitivity are interesting features in many applications, particularly in vibrations monitoring. Piezoelectric accelerometers have wide frequency range (0.1 Hz to 30 kHz), low power consumption and high "survival" to shock. Referring to an electrical circuit, the piezoelectric transducer is a capacitor, so its output signal is given in electric charge (Coulomb) and not in a voltage (Volts). The resistance connection to the piezoelectric face contacts performs its discharge with τ time constant equal to (R) resistance, multiplied by (C) capacitance of $(\tau = R \times C)$ element, whose values are near to MΩ resistance, and μF to capacitance among the piezoelectric faces. When a motion variation is applied to the accelerometer, the sensor senses a change in the excitation strength $(F = m \times a)$, generating an electrical charge proportional to: (q):

$$q = d_{ij} \times F = d_{ij} \times m \times a$$

in which q is the generated charge and d_{ij}, the piezoelectric material coefficient. The sensitivity is usually given in pC/g (Coulomb peak gravity) and PZT is the most commonly used material, because its piezoelectric constant is about 150 times larger than quartz, i.e., it is more sensitive and may be smaller. Piezoelectric accelerometers are indicated for high frequencies, not for measurements at low frequency, because they respond worst than the piezoresistive accelerometers [1, 10].

Piezoresistive accelerometers: these accelerometers, as the name implies, are implemented with semiconductors strain-gages sensors, allowing their miniaturization. Typically, they are implemented with two semiconductors strain-gages (half Wheatstone bridge configuration) or four semiconductors strain-gages (complete Wheatstone bridge configuration). They can provide protection systems against overload, preventing sensor damage due to high amplitudes. This accelerometer family is suitable for low frequencies, for example, below to 1 Hz, and can be used in static systems characterization, unlike piezoelectric accelerometers. They have a significant advantage, when compared to piezoelectric accelerometers; they can be used in inclination measurements, in which the acceleration is constant. Piezoresistive accelerometers are mass-produced since 1980 and used in various applications, including air bags control systems in cars [1].

Capacitive accelerometers: accelerometer with capacitive technology is another MEMS sensors family member that can be used in static systems. They have a significant advantage, when compared to piezoelectric accelerometer; they can be used in inclination measurements, in which the acceleration is constant. They are characterized by a stable frequency response to temperature function. In addition, the piezoresistive MEMS accelerometers are susceptible to contamination on the surface, which may cause serious stability problems. Because of these characteristics, some efforts have been made to develop MEMS sensors, using capacitive technology, having better stability than the piezoresistive accelerometers. However, capacitive sensors are inherently nonlinear and the small capacitances measurement of a miniaturized structure is very difficult due to parasitic effects and electromagnetic interference from the environment. With internal conditioning circuits, the capacitive accelerometers have a higher output signal compared to the piezoresistive accelerometers. Several sensors manufacturers have nowadays an interesting MEMS accelerometers portfolio with capacitive technology for acquisition [1].

Resonant accelerometer, thermal and gas: resonant accelerometers use the principle of pressure transducers by resonance. This accelerometer is based on the structure stiffness modification that supports the mass. The sensor consists of a resonator of two parallel beams, a mass and an anchor. The beams are interconnected, and also hold two joints that connect to the mass and anchor. Thermal accelerometers are manufactured by MEMS technology and like any other accelerometers have a seismic mass suspended by a beam, but in this case positioned next to a thermopile. The space among these components is filled with a gas heat conductor and the operating principle is due to heat transfer. They are extremely sensitive to interference such as ambient temperature and electromagnetic noise and do not have many applications nowadays. The gas accelerometer uses the same gas as a seismic mass. The gas accelerometer is capable to measure acceleration ranges from $\pm 1g$ to $\pm 100g$ and can measure both dynamic acceleration (vibrations) and static acceleration (e.g., gravity). Its use in large scale is still recent [10].

In many experimental situations, it is interesting that there is no cable connecting the transducer to conditioning system, mainly due to the involved distances, the difficult access to measurement points, the cables noise, among other factors. Telemetry systems by cellular phone, through Bluetooth, among others, are attached to the transducer, allowing the wireless interesting signal transmission. Currently the sensor integration technology with communication systems and digital electronics has allowed the tiny sensors development with built conditioners (for example, technology MEMS already mentioned in the text) and wireless, reducing costs in many experimental situations [1]. A measurement system based on wireless sensor consists basically on:

- ✓ sensor;
- ✓ signal conditioner (programmable amplifiers in general);
- ✓ multiplexing system;
- ✓ analogue (s) converter (s) to digital (s);
- ✓ microprocessor or microcontroller unit;
- ✓ supply system (depending on the backup cost);
- ✓ communication system, for example, a RF transceiver (Radio Frequency);
- ✓ storage information system (for example, a flash memory family).

With respect to wireless sensors network, several topologies are found, among them star, hybrid topologies (the example is the standard known as ZigBee), and various standards, such as IEEE802.11, Bluetooth (IEEE802.15.1 and IEEE802.15.2), IEEE802.15.4, IEEE1451.5, among others.

3. Experimental Section

3.1. Description of the System

Fig. 2 shows the block diagram of the developed experimental system.

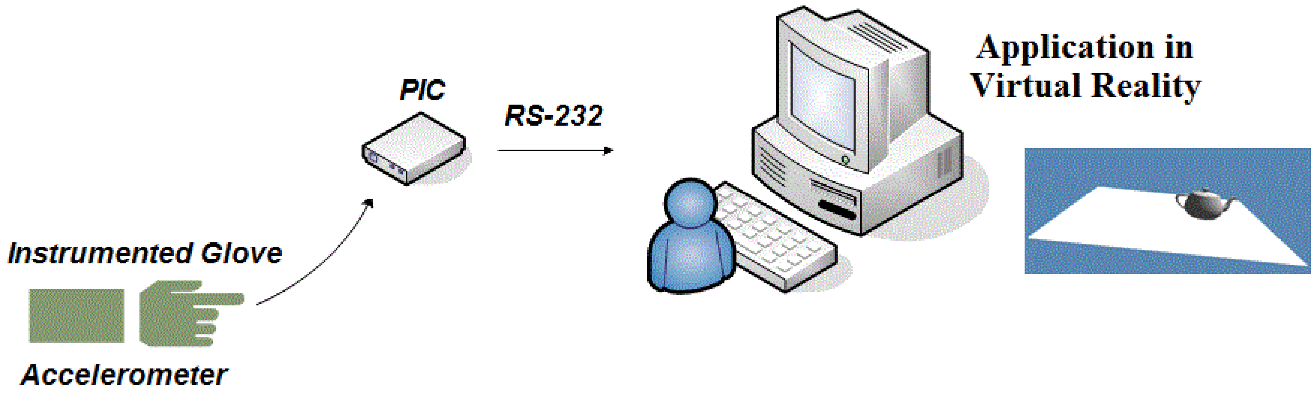

Fig. 2. Blocks diagram of developed experimental system.

This system consists of an ADXL202E accelerometer sensor (©Analog Devices) that has two measurement axes (bi-axial accelerometer) and a measurement range of ±2 g to PWM output (Pulse Width Modulation). In this sensor, the pulse width is proportional to the measured acceleration. The filter that was implemented on XFILT and YFILT accelerometer pins with 50 Hz bandwidth determines the sensor resolution. According to the parameters, the accelerometer noise is 200 μV. Thus, the sensor resolution is presented, according to the following equation:

$$R = a\sin(200\mu\sqrt{50}) = 0{,}08^{\circ}$$

We used PIC16F628A microcontroller that has a voltage range from 2 V to 5V and a resolution of 0.4 μs (one processor cycle). The PIC microcontroller has PWM reader and generates an interruption every edge's pulse rise or fall.

3.2. Graphical User Interface *(GUI)*

In this work we used tools such as OpenGL and GLUT graphical user interface. OpenGL is a free API used in graphic computer, for development of graphics applications, 3D environments, games, among others. Basically there are hundreds functions, which provide access to virtually all the video hardware features, such as current colors, transparency level, lighting calculations, fog effect, and so on. GLUT (OpenGL Utility Toolkit) is a library of functions for OpenGL, whose main goal is the operating system abstraction, causing the applications to be multiplatform. The library has functionality to create and control windows, and also event handling of input devices (mouse and keyboard). There are also routines for the pre-defined three-dimensional shapes design.

We developed a simple graphical interface, using the OpenGL program to allow monitoring a plan movement through the determined inclination angle from ADXL accelerometer outputs. Fig. 3 shows the used graphical interface to simulate the movements applied with the glove. As the user moves the glove, the plan suffers the due applied inclination and the kettle tends to slide by the plan. Below follows a routine developed for this plan developed 2D.

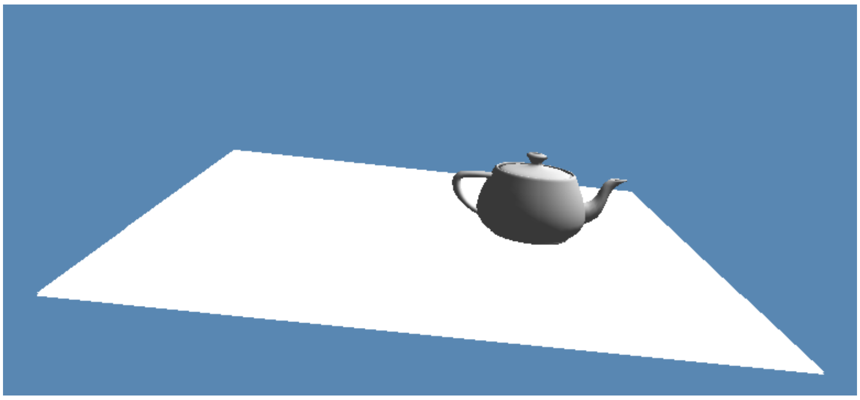

Fig. 3. Inclined plan through the movement of the instrumented glove.

Function responsible for coordinated rotation:

```
*/
void rotation_camera()
{
        glRotatef( -g_fSpinY_L , 1.0f, 0.0f, 0.0f );
        glRotatef( -g_fSpinX_L, 0.0f, 1.0f, 0.0f );
}
void rotation_glove()
{
        glRotatef( - angle_y, 1.0f, 0.0f, 0.0f );
        glRotatef( -angle_x, 0.0f, 0.0f, 1.0f );
}
/*
Perform the drawing surface
*/
void Surface()
{
        glPushMatrix();
        {
                glColor3f( 1.0f, 1.0f, 1.0f );
                glInterleavedArrays( GL_N3F_V3F, 0, g_floorQuad );
                glDrawArrays( GL_QUADS, 0, 4 );
        }
        glPopMatrix();
        glPushMatrix();
        {
                glColor3f( 1.0f, 1.0f, 1.0f );
                glTranslatef( 0,-0.03 ,0 );
                glInterleavedArrays( GL_N3F_V3F, 0, g_floorQuad2) ;
                glDrawArrays( GL_QUADS, 0, 4 );
        }
        glPopMatrix();
}
/*
```

Function responsible for the design of objects:

```
*/
void display(void)
{
	glClear( GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT );
	glMatrixMode( GL_MODELVIEW );
	glLoadIdentity();
	glTranslatef( 0.0f, -2.0f, -15.0f );
	glScalef(escala, escala, escala);
	rotation_camera();
	//
	// Creates a small ball of light in position
	//
	glDisable( GL_LIGHTING );
	glPushMatrix();
	{
		glLightfv( GL_LIGHT0, GL_POSITION, g_lightPosition );
		glTranslatef( g_lightPosition[0], g_lightPosition[1], g_lightPosition[2] );
		glColor3f(1.0f, 1.0f, 0.5f);
		glutSolidSphere( 0.1, 8, 8 );
	}
	glPopMatrix();
	rotation_glove();
	//
	// Draw surface
	//
	Surface();
	glEnable( GL_LIGHTING );
	glEnable(GL_DEPTH_TEST);
	//
	// Create an object.
//
	glPushMatrix();
	{
		glTranslatef( posicao_objeto_x, posicao_objeto_y, posicao_objeto_z );
		glColor3f(1, 0, 0);
		switch (objeto) {
			case 1:
				glutSolidTeapot( 1.0 );
				break;
			case 2:
				glutWireTeapot( 1.0 );
				break;
		}
	}
	glPopMatrix();
	glutSwapBuffers();
}
/*
```

3.3. Conditioning of the System

The developed system consists of an accelerometer, whose PWM output is related to the measured acceleration. Accelerometers output pins are connected directly to the microcontroller (PIC) input port, In this microcontroller some interruption is generated at each ascent or descent edge from the PWM signal and a 16-bit timer is used as a counter for PWM.

At the ascent edge, the PIC saves the value of the timer counter and in the descent edge just reads the counter and calculates the difference from both edges, obtaining the parameter T_1 (which is the signal time at a high level). After this first cycle, in the next ascent edge, the PIC reads the counter and calculates the difference with the first value again, but this time resulting in T_2, which is the signal total period. After this new cycle, yet in this ascent edge, the PIC resumes the process, saving this new value as the initial value and so forth.

This information packet is transmitted to the MAX232, which reports to the computer's serial port. Below the packet format sent by the PIC is showed:

<ST><ST><CMD><MOD><DUTY_L><DUTY_H><PERIOD_L><PERIOD_H><END>

where:
<ST> = 'I' (letter 'i' capitalized)
<CMD> = 'M'(letter 'm' capitalized)
<MOD> = 0 ou 1 (id PIC CCP module – inputs X and Y accelerometer)
<DUTY_x> = period of the duty cycle of processor cycles PIC: Fosc=(10.726.834/4)Hz, Tcy=1/Fosc
<PERIOD_x> = period of full course also in processor cycles
<END> = 'E' (letter 'e' capitalized)

The duty cycle period is equivalent to T_1 in the accelerometer datasheet and the complete cycle period is T_2. PIC may also receive commands, sending a packet in a format like:

<ST><ST><CMD><END>

The PIC receives commands that are
CMD = 'B': access the bootloader (to reprogram the PIC)
CMD = 'C': calls calibration function

Pthreads are used to make the program segmentation, making routines run in parallel. One of these routines is responsible for receiving data from PIC, unpacking them and making conversion to be worked. The Pthread 1 executes READ_PORT, triggering a functions routine. The Pthread 2 performs the DATA_LOOP function and is responsible for calculating the angle and acceleration with the period and Duty Cycle received from Pthread 1, thus achieving an average of "n" readings to increase the measurements reliability. The parameters for the design of OpenGL 3D screen is loaded, configured and initialized in the program main body. Temporal OpenGL functions for object dynamic calculations, simulating a limited gravity upon the same are also initialized.

Another function is responsible for temporal smoothing of the plan angle reading with the glove, taking from time to time the given angle by Pthread 2, in order that the table's current position can approach to the reading. Fig. 4 briefly shows the main block of the routine.

Main			
pthread 1	read_port() receive_data: infinite loop	find_data (), unpacking	save buffer (): saves in buffer_data_ok after 10 readings
pthread 2	data_loop(): loop infinito	processes data () handle buffer data_ok calculates average calculate acceleration calculates angle writes new angle x writes new angle y	

Fig. 4. Schematic routine's program.

3.4. Calibration and Linearization of Experimental System

To use the system, the user must wear a glove (see photo in Fig. 5) that has the accelerometer sensor. Soon after, the system displays a message requesting the preliminary tests for the system calibration. Guidelines are presented on the computer display and calls for certain steps related to the hand's spatial positioning to the right system calibration.

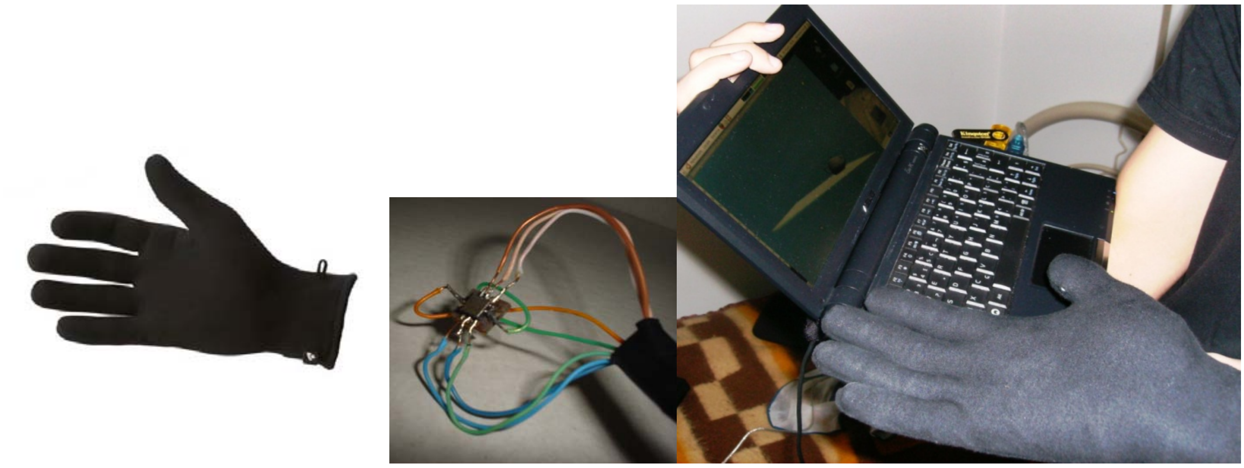

Fig. 5. Glove's picture with internal sensor.

After instrument calibration, as proposed by the manufacturer, we obtain the accelerometer linearization, which was determined in the range from -1g to +1g as the sensor's position. To find the sensitivity, we applied the equation:

$$S_{x,y} = \frac{(A - B)}{2g}$$

in which S is the sensitivity in the x or y-axis, A is the accelerometer output for the axis oriented at +1g, and B is the accelerometer output to the axis oriented at -1g. Based on acceleration, we can calculate the angle, using the following expression:

$$Angle\ X = \operatorname{asin}\left(\frac{\frac{T_1}{T_2} - 0{,}5}{\frac{S_x}{g}}\right)$$

$$Angle\ Y = \operatorname{asin}\left(\frac{\frac{T_1}{T_2} - 0{,}5}{\frac{S_y}{g}}\right)$$

in which S is the sensitivity in the X or Y-axis, T_1 is the Duty Cycle (PWM signal in high level time) and T_2 is the reading time. Fig. 6 show the transfer functions for the interest angles of the developed system.

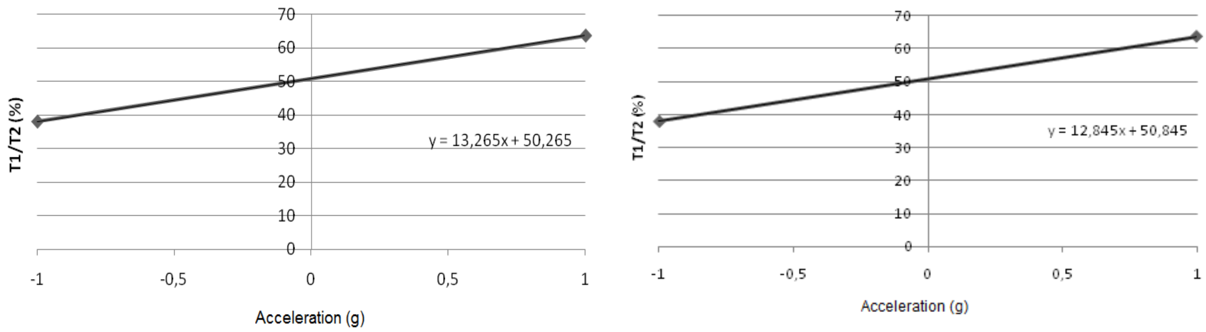

Fig. 6. Transference curve to the: (a) X angle; and (b) Y angle.

Thus, the transference curve inclination, $S_x = 13{,}265 \ \ and \ \ S_y = 12{,}845$, gives the sensitivity of the developed system.

3. Results and Discussion

Essays relating the acceleration due to the variation of the plan inclination angle were performed and are represented by Tables 1 and 2.

Table 1. Measurements (average) carried out by varying the X inclination angle.

Angle X (º)	Gravity (g)
-90	-1,0029
-76,3	-0,9715
-65,14	-0,9073
-61,99	-0,8828
-58,54	-0,853
-14,3	-0,2469
-9,95	-0,1729
-14,3	-0,2469
26,46	0,4455
34,68	0,569
67,63	0,9247
90	1,1633

Table 2. Measurements (average) carried out by varying the Y inclination angle.

Angle X (º)	Gravity (g)
-90	-1.0029
-76.3	-0.9715
-65.14	-0.9073
-61.99	-0.8828
-58.54	-0.853
-14.3	-0.2469
-9.95	-0.1729
-14.3	-0.2469
26.46	0.4455
34.68	0.569
67.63	0.9247
90	1.1633

The statistical procedure used to validate the experimental data is called "Design of Experiments with Several Factors – two-factor factorial experiments" [11], i.e., the variability of observed data observed with two controllable factors: different types of angles (factor A: twelve different angles: -90º to 90° - see Tables 1 and 2) and different axes (factor B: X and Y of accelerometer). The variable of response for this test is the gravity (*g*) of the accelerometer. The observations can be described approximately by the following linear model:

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk} \quad \begin{cases} i = 1,2,\dots,a \\ j = 1,2,\dots,b \\ k = 1,2,\dots,n \end{cases}$$

where μ is the overall mean effect, τ_i is the effect of the i^{th} level of factor *A*, β is the effect of the j^{th} level of factor *B*, $(\tau\beta)_{ij}$ is the effect of the interaction between *A* and *B*, and ε_{ijk} is a random error component having a normal distribution with mean zero and variance σ^2. This experimental design is a ***completely randomized design***. The three hypotheses that we will test are as follows:

1. $H_0{:}\tau_1 = \tau_2 = \cdots = \tau_a$, no main effect of factor *A*, $H_1{:}$ at least one $\tau_i \neq 0$

2. $H_0{:}\beta_1 = \beta_2 = \cdots = \beta_b$, no main effect of factor *B*, $H_1{:}$ at least one $\beta_j \neq 0$

3. no interaction, $H_1{:}$ at least one $(\tau\beta)_{ij} \neq 0$

will be used $\alpha = 0.05$ (significance level). The sums of squares for the analysis of variance (two-away analysis of variance) are computed - the Table 3 shows the analysis of variance for a two-factor factorial experiments (ANOVA is summarized).

Table 3. Analysis of variance for experiment.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	$\approx F_0$
A	0.0001	1	0.0001	5.47
B	3.0675	3	1.0225	1859
AB	0.0075	3	0.0025	4.54
Error	0.0089	16	0.0006	
Total	3.0084	23	0.1308	

According to the results summarized in Table 3 and to $f_{0.05;11;16} \cong 4.49$, $f_{0.05;3;16} \cong 3.24$, it is possible to conclude that the effect due to the : twelve different angles (factor A) are significant, the effect due to the X and Y axes (factor B) are significant and that the AB interaction is significant. With this procedure, it was verified that the three controllable factors are significant, i.e. the acceleration result is affected.

4. Conclusions

The designed and developed glove was capable of achieving the expected results with considerable accuracy levels and efficiency, considering the use of a single sensor with costs below all the gloves that are available today in the market. We put the glove sensor on the hand top, giving the user greater comfort in movements and to allow him to grab objects while wearing the glove.

With this tool development, new forms of human gestures analysis and modeling become viable and comparisons with alternative techniques such as computational vision become possible, as simulation equipment and hands movements capture.

The developed system limitation is an important point to be discussed, because it can influence the measurement system and the prototype cost. The sensor provides limitations for the developed instrumental glove, as a small acceleration measuring range, because a low cost accelerometer is used, compared with the used sensors in large research projects. Another relevant factor is that a single sensor captures the plan inclination that recognizes only the hand plan movement and not others, like the fingers movements and joints.

The option of inserting textures is useful in improving the quality of the scenery objects, but becomes a limitation, because the images insertion increases the files size and decreases the animations processing speed. Therefore, we conclude that the insertion of textures should be evaluated, when we want to improve the simulation realism, confronting this way with the image speed.

Some improvements are needed, such as putting more sensors on the glove, for the project to become more reliable and to be deployed in all the virtual reality fields. Positioning motion sensors in body parts, such as the palm of the hand or wrist, it is possible to monitor other degrees of movement freedom and consequently allow the virtual hand represents them. Other required sensors would be based on the hand articulation and arm. Another improvement that can be implemented is the system adaptation to recognize the coordinates (x, y) and the position for which the 3D object is oriented, in accordance to changes in motion.

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