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A New Device for Assessing Subjective Haptic Vertical

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Abstract—**In otoneurology the analisys of Subjective Vertical perception is a useful tool to investigate macular function and central otolithic pathways. The Subjective Vertical is perceived using visual, vestibular and proprioceptive subsystems.**

In this work we propose a new device that can assess just the tactile / somatosensory subsystem contribution compared to other commercial devices that investigate the other subsystems.

The developed instrumentation is made by a bar equipped with two orthogonally oriented Micro Electro Mechanical System accelerometers that transmit data to a remote visualization apparatus. During the examination, the patient handles the bar and must align it along the direction perceived as "vertical".

I. INTRODUCTION

The equilibrium system is based upon complex interactions among different areas of the nervous system, that work together with other sensory subsystems (visual, vestibular, somatosensory) to let the brain know the body position in tri-dimensional space, to assume the standing position and to orient the body with respect to the gravitational field.

In otoneurology the analisys of Subjective Vertical (SV) perception raised some interest, since it is a useful tool [1][2] to investigate the correct function of vestibular maculae and central otolithic pathways. This tool is meaningful in patients complaining about vertigo and dizziness.

Inputs from visual, vestibular and somatosensory systems contribute to verticality perception. Changes in these inputs (peripheral pathology) or deterioration of input elaboration abilities (central pathology) may affect the SV.

We can measure subjective vertical perception according to three different sensory conditions: visual, haptic and postural. [2][3]

Some devices are available to assess the equilibrium system. For instance, the device named "EquiTest" by NeuroCom [4] can assess the equilibrium performing a stabilometric examination to a patient standing on a platform.

The platform is internally equipped by load cells that can estimate the barycentric vectorial component of patient over the horizontal plane, and by servo motors that can modify the platform tilt during the examination. During the first phase of examination, the patient must keep their upright position using the visual, the vestibular and the proprioceptive systems together. In the second phase the patient is asked to close his eyes in order to exclude the visual subsystem. In the last phases, platform dynamic changes reduce the inputs from proprioceptive and/or visual subsystem, and information about the vestibular subsystem only is obtained. This device makes possible to estimate the contribution of each single subsystem to keep the standing position, but gives no information about the patient verticality perception.

Other devices [5] evaluate only the visual component of the SV (Subjective Visual Vertical).

Some authors [6] use an apparatus for investigating the tactile / haptic vertical. The apparatus is formed by a rod rotating on a swivel fixed at the center of a vertical board. The angle between rod axis and the vertical can be instantaneously read by an operator. With this device the patient can obtain tactile information about the rod position due to the pivot; furthermore this device provides information about the subjective haptic vertical only on the frontal plane.

In this work we propose a new device that can assess just the tactile / haptic contribution to the verticality perception. The proposed device is a no-tie system using two orthogonally oriented Micro Electrical Mechanical System (MEMS) accelerometers. It is very compact, portable and cheap.

With respect to traditional devices it allows to investigate also the sagittal plane and is able to track the bar during the whole positioning movement. The tracking can retrieve more useful indexes such as patient's ability to keeping the

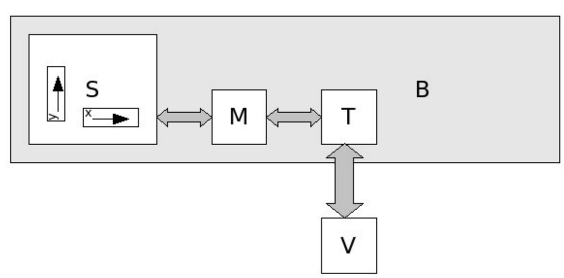

Fig. 1. Haptic bar blocks: tieless bar B, dual axis (x and y) accelerometer S, microcontroller M, transmitting system T, receiving and visualization system V.

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bar in the final position, or speed and accuracy of the movement.

Moreover, this device has no reference points such as the pivot found in other devices.

II. Matherial and Methods

A. Clinical Protocol

The Subjective Haptic Vertical Test (SHVT) is performed with the patient in the upright position (Romberg position) without shoes, in a quiet room. The patient handles the bar with his preferential hand and keeps her head straight.

The subject task is to orient the bar upright along the direction perceived as "vertical".

The patient aligns the bar in a completely dark environment, keeping her eyes closed to avoid visual information.

The SHVT is executed with two different starting positions: 40 degrees to the right and 40 degrees to the left. The bar is set in its starting position by the examiner.

The patient repeats the SHVT wearing a neck band in order to keep the neck in a controlled vertical position.

The clinician controls the SHVT using a remote visualization system.

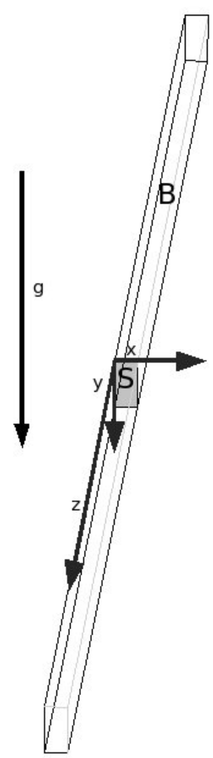

Fig. 2. Schema of the haptic bar showing the relative position of the two accelerometer axis (x and y) and the bar longitudinal axes (z)

B. The Haptic Bar

The proposed device is made by a 0.3 meter long bar, with a rigid and undeformable body and a handle at its center of mass. The bar total weight is about 20 g. Inside the bar is located the circuitry used to assess the angular position between the bar itself and a vector oriented as the local gravitational vector (*g*). The angular position is transmitted to an external computation and visualization system. Data transmission is performed in wireless mode, to prevent any obstacle to the patient during the examination and avoid external masses (e.g. data transmission wires) that could provide information about the gravitational field to the patient.

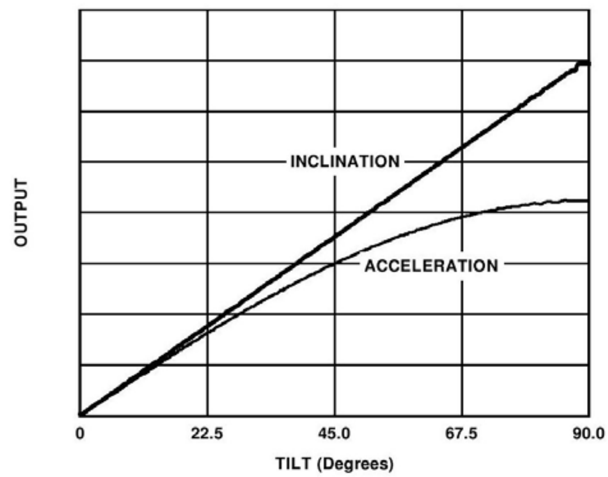

Fig. 3. Acceleration and inclination angle behavior versus tilt angle (taken from ADIS16201 Data Sheet)

C. Working Blocks

The haptic bar is composed by the following working blocks, as reported in Fig. 1

- a tieless bar B
- a static acceleration sensor S
- a microcontroller M
- transmission system T
- a receiving and visualization system V

- Tieless bar B

A long and narrow tube makes the bar and hosts the electronic circuitry inside. It is made by a rigid material with a handle in its center. The bar section can be rectangular or square.

- Static acceleration sensor S

An integrated circuit ADIS16201[7] manufactured by Analog Devices Inc. containing two MEMS accelerometers orthogonally aligned with an error less than +-0.2 degrees is firmly positioned inside the bar, at its barycenter.

When it is close to the horizontal plane (±15 degrees) the device works as an inclinometer, with ±0.25 degrees accuracy, but when it is in the operative range of ±60 degrees its accuracy becomes ±1.5 degrees.

The device is positioned in a way that both accelerometer axis (x and y) are parallel to the rectangular section edges of the bar and orthogonal to the bar longitudinal axis, as in Fig. 2.

We chose a MEMS accelerometer for its low weight and reduced size, that makes easy to integrate the sensor inside the haptic bar without appreciably increasing its heaviness. The accelerometer measures 9.327mm x 9.327mm x 3.90mm.

- Microcontroller M

The microcontroller drives the accelerometers, decodes and filters the signals coming from their outputs, and transmits data to the visualization system. The 8-bit PIC16F628A microcontroller [8], manufactured by Microchip, has been used.

Sampled data are submitted to a low pass filter to reduce noise and extract only static accelerations.

In our prototype we implemented a 5th order moving average algorithm. Sampling frequency was 10Hz.

- Transmission system T

The transmission system sends microcontroller processed data to the visualization system in a wireless mode, to avoid cables that could hinder the patient during the test. It is composed by a SMD module compliant with the CE-ETS-30020 European Directive and an integrated and miniaturized antenna for radio-frequency transmission.

- Receiving and Visualization System V

This block receives signals from T and provides the interface to a personal computer where an ad-hoc developed software can read data, draw data tracks over time and show the bar position with respect to a 3D environment. The software can save data and tracks too.

D. Measuring Methods

In static conditions and after being calibrated, a typical MEMS accelerometer gives a value in m/s^2 that represents the vectorial component of gravitational acceleration over its axis.

The angle ρ between accelerometer axis and *g* vector can be calculated by

$$\rho = a\cos\left(\frac{Ag}{|g|}\right) \quad (1)$$

where A*g* is the value of the *g* vectorial component as read by the accelerometer.

Hypothetically a single accelerometer parallel to the longitudinal axis of the bar would be sufficient to achieve the angle between the bar itself and the *g* vector.

Unfortunately, when an accelerometer is oriented along the *g* vector, its working conditions are imprecise because large angular movements give limited acceleration increments only. (Fig. 3)

Moreover, in these vertical conditions, even small errors in acceleration measures will have a big effect on angular position computing , as seen in Fig. 4.

In view of the fact that the patient must align the bar along the *g* vector during the test, using a single accelerometer along the longitudinal axis of the bar is practically unfeasible.

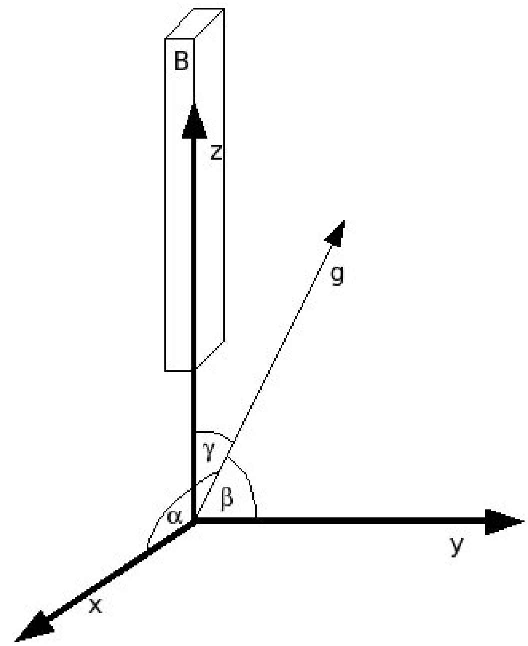

Fig. 5. Spatial reference used in our system. The dual axis accelerometer reads α and β angles from which γ tilt angle is calculated.

We decided to use two orthogonally aligned accelerometers with both axis (x and y) standing at right angles to the longitudinal axis of the bar (z). (Fig. 2).

This configuration allows optimal working conditions during the test, having both accelerometers orthogonal to the gravitational vector when the bar is vertically oriented.

According to (1), we can compute the α and β tilt angles, that are respectively defined between x and y axes, and *g* vector (Figure 5).

The angle between the subjective haptic vertical and the gravitational vector *g* is called γ.

If we choose the x y z axes as a spatial reference, the angles α β γ between each axes and *g* vector are related according to the direction cosines law:

$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$$

The angle γ between z and *g* can then be derived:

$$\gamma = a\cos\sqrt{1-\cos^2\alpha - \cos^2\beta}$$

III. Discussion

We developed a new device for assessing the subjective haptic vertical. This new device gives several advantages with respect to commercially available devices to measure the tilt:

- the device communicates in wireless mode to a reader station
- it has no helping reference points
- it works with the best accuracy close the g vector
- it records the motion dynamic during bar alignment

During the examination acceleration data read from the sensor S should be restricted to gravitational accelerations, in order to allow a good estimation of the angle g.

Accelerations caused by the patient movements while vertically aligning the bar and possible random accelerations produced while keeping the bar in its final position should be conveniently discarded.

Previous experiments [9] show that is possible to partially solve this problem using a low-pass filter.

In our setting the angle measurement is performed in a static condition, when the patient ends the bar aligning movement.

We implemented on the microcontroller a 5^{th} order moving average low-pass filter which worked well.

Another considered issue regards the environment parameters that can diversely affect accelerations data coming from accelerometers. Each accelerometer has its own 0g offset value and 1g gain factor, which depend on temperature, pressure, humidity etc and are different in each accelerometer.

In order to obtain more accurate readings, we set up a calibration procedure where the 4 longitudinal faces of the bar are one after another placed over a perfectly horizontal surface. The microcontroller reads the values A_{a0g},A_{+1g},A_{b0g}, A_{-1g} with its axes respectively positioned to 0g, +1g, 0g, -1g. For each accelerometer axes, it is possible to calculate 0g offset:

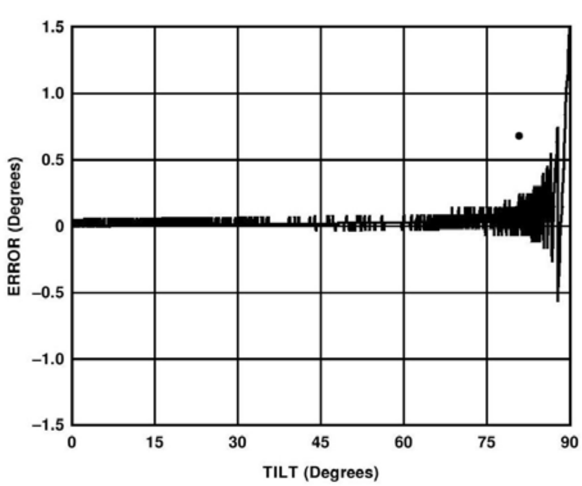

Fig. 4. Inclination Quantization Error versus tilt angle. (taken from ADIS16201 Data Sheet)

$$Offset0g = \frac{A_{+1g} + A_{-1g}}{2}$$

and 1g gain:

$$|g| = \frac{A_{+1g} - A_{-1g}}{2}$$

Obtained 0g offset and |g| are stored in the microcontroller EEPROM until the execution of the next calibration procedure.

IV. Results

A prototype of the bar for assessing subjective haptic vertical has been realized. In the IRCCS Medea Institute otoneurology laboratory we initially studied a group of normal adults and few patients complaining about vertigo (benign paroxysmal positional vertigo and vestibular unilateral ipofunction). First results are encouraging.

References

[1] A. M. Bronstein, D. A. Pérennou, M. Guerraz, D. Playford, P. Rudge, "Dissociation of visual and haptic vertical in two patients with vestibular nuclear lesions", *Neurology*, Nov. 2003, pp. 1172-1173.

[2] J. A. Shape, "What's up, doc? Altered perception of the haptic, postural, and visual vertical", *Neurology*, Nov. 2003, pp. 1260-1262.

[3] D. Pèrennou, "Towards a better understanding and quantitative assessment of pushing, a postural behaviour caused by some strokes", *Annales de Redaptation et de medecine Physique*, Oct. 2004.

[4] F. Ionescu, C. Dubreuil, C. Feber-Viart, "Physiological changes in balance control of adults aged 20 to 60 years assessed with Equitest", Annales d'Otolaryngologie et de Chirurgie Cervico-Faciale, Nov. 2005, pp.231-235.

[5] M. Cavalleri, G. Reni, U. Pozzoli, D. Brambilla, "A new subjective Visual Vertical Assessment System", in *Proc. 20th Ann. Intern. Conf. IEEE/EMBS*, Hong Kong, 1998, vol. 4, pp. 1808-1810.

[6] E. Gentaz, M. Badan, M. Luyat, N. Touil, "The manual haptic perception of orientations and the oblique effect in patients with left visuo-spatial neglect", *Cognitive Neuroscience and Neuropsycology*, Vol 13 No 3 March 2002

[7] Analog Semiconductor,"ADIS 16201 Programmable Dual-Axis Inclinometer/Accelerometer,, , Available: http://www.analog.com/UploadedFiles/Data_Sheets/37287829ADIS16201_0.pdf

[8] Microchip Semiconductor: "PIC16F628A Flash-based 8 bit CMOS Data Sheet", Available: http://ww1.microchip.com/downloads/en/DeviceDoc/40044D.pdf

[9] R. E. Mayagoitia, A. V. Nene, P. H. Veltink, "Accelerometer and rate gyroscope measurement of kinematics: an inexpensive alternative to optical motion analysis systems", *Journal of Biomechanics*, 2002, pp. 537-542.