Pickup of Head Movement in Vestibular Reflex Experiments with an Optical Fiber Gyroscope

S. Donati, *Member, IEEE*, V. Annovazzi-Lodi, *Member, IEEE*, L. Bottazzi, and D. Zambarbieri, *Member, IEEE*

Abstract—**We show that, in studying eye–head coordination, the rotation of the head can be measured with the aid of a fiber optics gyroscope mounted on a helmet worn by the subject, and that the performances of this approach are considerably better than those of currently used sensors. After presenting the specifications required in head rotation measurements, we report details on the used gyroscope and on its interconnection to the acquisition system and discuss experimental results of head rotation measurements made by the gyroscope and the potentiometer sensor.**

I. INTRODUCTION

CLINICAL examination of the vestibulo-ocular reflex (VOR) is normally performed by considering the nystagmic eye response induced by passive head rotations in darkness. Passive head rotations are obtained by placing the subject on a rotatory chair which needs a complex and expensive experimental setup to be controlled. Nevertheless, it has been recently demonstrated that the same nystagmic response can be induced by active head rotation in darkness [1]. In this case, only a system recording head rotation in space is needed.

Several kind of head rotation sensors are currently used, the most common being the resistive transducer (or potentiometer), but also the piezoelectric rate-sensor and the magnetic (induction) coil sensors can be used. All of them have one or more unsatisfactory performance, either in dynamic range and accuracy or because of the excessive size or the mechanical constraints imposed to the patient if the sensor has a fixed part while the head rotates. The optimal specifications for head rotation recording are those reported in Table I. In addition to these data, it is usually required that size and weight be small respect to those of the helmet, and that a minimum of wires connects the helmet to the acquisition instrumentation.

The fiber-optics gyro (FOG) easily matches all the above specifications and, in addition, it can be battery powered so that no interconnection wires are required if, as shown below, signals are sent to the instrumentation via an optoelectronic infrared link.

II. THE DEVICE

The FOG is probably the best studied and developed optical fiber sensor. Prompted by the applications in avionics and in the military for attitude reference and inertial navigation platform, the FOG has matured to the point of an industrial product available from several manufacturers, with unparalleled performances and well-understood technology of fabrication. There are several excellent reviews and textbooks available on the FOG [2], [3], and thus we simply outline here some practical features of it. Basically, the FOG is made up of some 100 m of fiber, wound on a coil and with the pigtails ends connected to a beamsplitter fiber-coupler. Light is fed into the coupler by a laser or a superluminescent light-emitting diode (LED). In the coil, two waves are launched in opposite directions by the coupler, and because of the Sagnac effect, these waves undergo a slightly different optical phaseshift, let say it Φ, which turns out to be proportional, $\Phi = \kappa\Omega$, to the angular velocity of rotation Ω of the coil in an inertial reference frame. The proportionality constant is found as $\kappa = 8\pi NA/\lambda c$, where A is the area of the coil, N the number of fiber turns, λ the wavelength, and c the speed of the light [in practical FOG's, κ ranges from 0.1 to 1° °C/s]. After propagation in the coil, the waves coming back to the coupler are superposed and detected at a photodiode whose output current carries the phaseshift (or angular velocity) information, in the form $I = I_0(1 + \cos\Phi)$.

Several important refinements are then necessary to get the top sensitivity [2], [3] in Ω (down to 0.01°/h), such as using a polarization holding monomode fiber to ensure reciprocity, and a phase modulator to get the sign and a good linearity.

Important to note, after being pushed to the top performances in sensitivity as required in the avionic area where high costs can be tolerated, the FOG is presently brought into the reach of low-cost areas like the automotive and the robotics, where medium-low performances are quite adequate.

The FOG unit we have used [4] in the experiments of head rotation pickup belongs to the class of medium performance and price, and has the basic specifications reported in Table II. The conformity to all of these specifications was first checked by acquisition of data on a PC with the unit working under the appropriate stimuli. The unit was thus determined to be fully compliant with the requirements of Table I.

The unit has a serial translator-transistor-logic (TTL) interface for the digital output, which can be related either to angular position or to angular rate. This interface was connected to the computer via a wireless infrared link. A detailed analysis and the design rules of a diffused-light infrared transmission have been presented elsewhere [5]. Using

---

Manuscript received December 11, 1996; revised January 17, 1997.

S. Donati, V. Annovazzi-Lodi, and L. Bottazzi are with the Dipartimento di Elettronica, Università di Pavia, Pavia, Italy.

D. Zambarbieri is with the Dipartimento di Informatica e Sistemistica, Università di Pavia, Pavia, Italy.

Publisher Item Identifier S 1077-260X(96)09701-8.

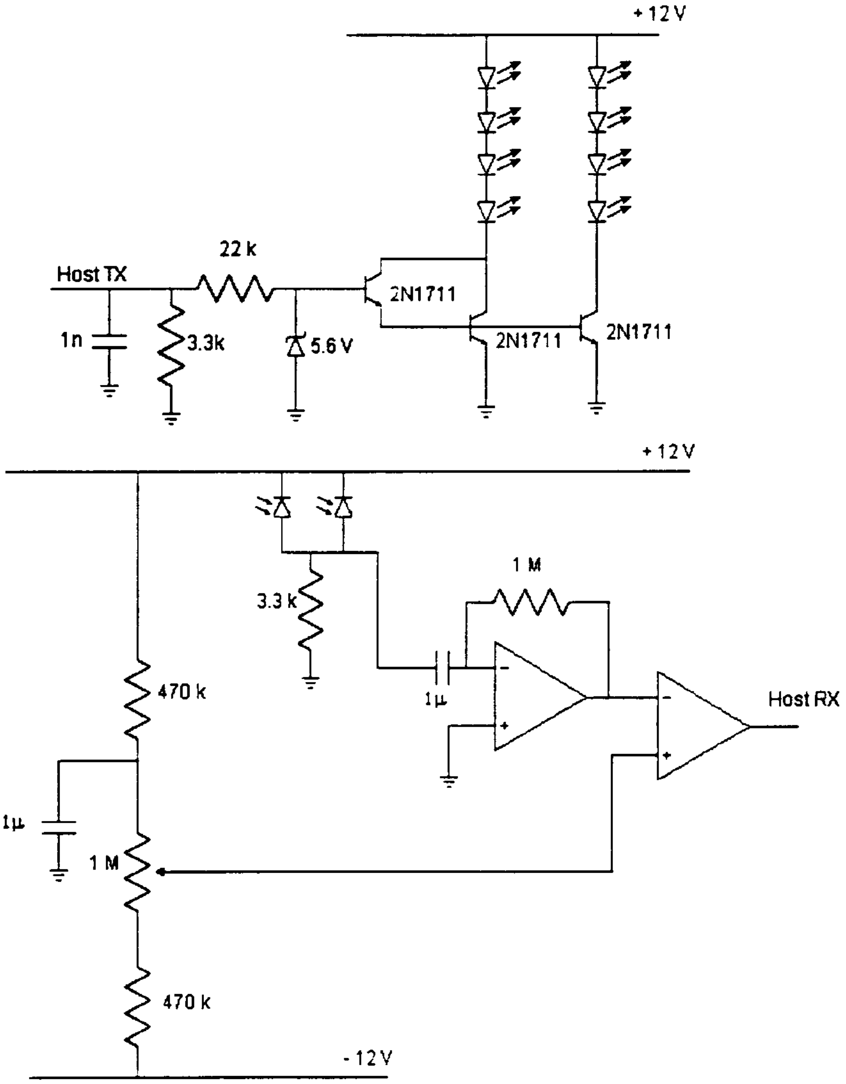


Fig. 1. Optoelectronic wireless interface for the gyro/computer interconnection: (top) schematics of the transmitter and (bottom) receiver.

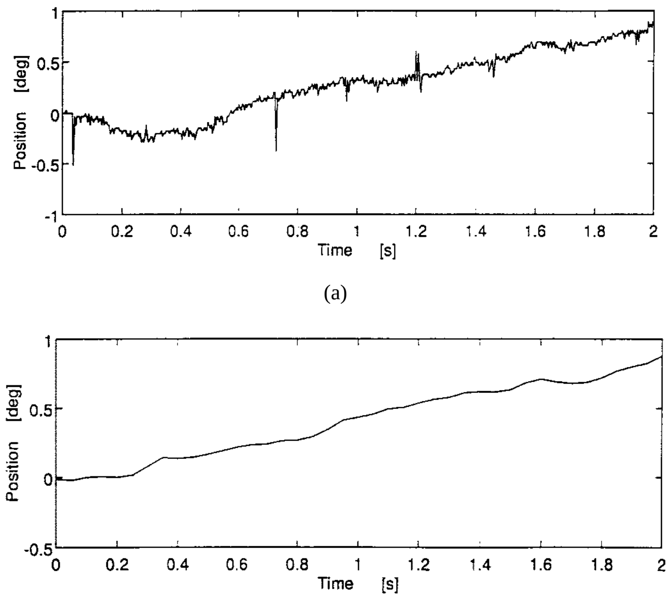
TABLE I

Parameter	*Position*	*Velocity*	*Acceleration*
Input Range	± 90 °	± 600 °/s	± 10000 $°/s^2$
Bandwidth	10 Hz	10 Hz	10 Hz
Offset	not critical	± 0.01 °/s	± 0.0002 °/s
Linearity	1 %	5 %	10 %
Rms Noise	1 °	0.01 °/s	0.0005 $°/s^2$
Drift	± 0.01 °/s	± 0.0002 (°/s)/s	0

TABLE II

Input range	± 100 °/s
Power supply	12 VDC - GND
Current	270 ÷ 280 mA
Weight	525 g
Offset	< 0.02 °/s
Scale factor error	1 % max
Scale factor nonlinearity	2 % max
rms Noise	< 0.02 °/s
Cutoff Frequency	10 Hz

those results, and the simplifying circumstance that in our case we can maintain direct sight, a simpler design based on LED's ($\lambda = 950$ nm) and photodiodes came out, as illustrated by the schematics of the transmitter (Fig. 1, top) and receiver (Fig. 1, bottom) we have realized and used to interconnect the FOG and the computer up to 2-m distance, all with a power supply from a rechargeable battery. The overall size of the complete system mounted on the helmet is 10 × 10 × 3 cm. In the software of data acquisition and processing, a *hunt routine* was inserted to avoid errors due to loss of a large amount of data in case of accidental shielding of the infrared link.



(a)

(b)

Fig. 2. Head rotation signals from simultaneous recordings by (a) a standard potentiometer system and (b) by the gyro (integral of rotation rate signal).

III. POTENTIOMETER VERSUS FOG

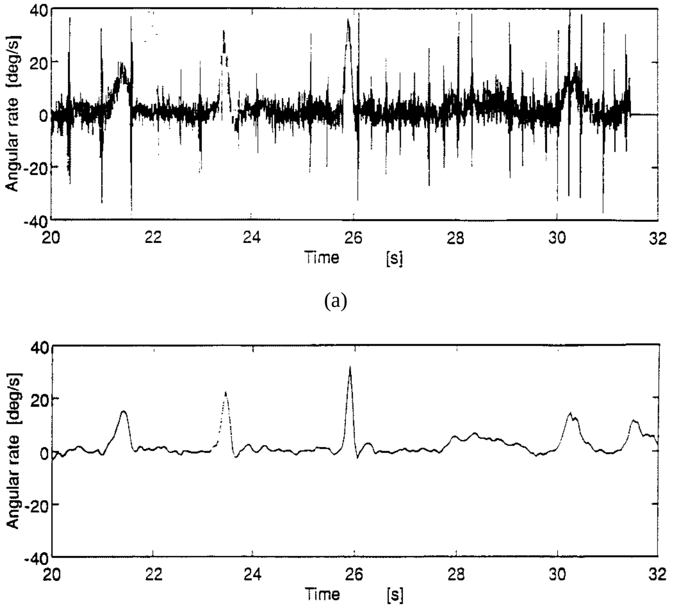
The potentiometer is one of the devices most commonly used for recording head rotation because it is inexpensive and easy to use and calibrate. Therefore, a direct comparison has been made between potentiometer and FOG performances by recording simultaneously head rotations with both devices mounted on the subject helmet. The two position signals are coincident, but the FOG signal displays much less noise than the potentiometer, and this can be attributed to the wiping contacts (Fig. 2).

As regards to angular velocity (i.e., the time derivative of the head rotation angle), Fig. 3 shows that the potentiometer signal is even more noisy, and how it becomes difficult to recognize the waveform pattern. Worth for the comparison, the potentiometer signal has already been filtered after acquisition through a specific digital-filtering *routine* (bandwidth 10 Hz), whereas the FOG signal was unfiltered.

Also, the FOG is better for patient comfort than the potentiometer, which requires cardan joints for shaft actuation and has some stiffness.

IV. ACTIVE HEAD ROTATION EXPERIMENT WITH FOG

A test has been performed in which the subject was asked to move his head in the dark. Eye movements were recorded by conventional electro-oculography and the head rotation by the FOG system. Eye, head, and gaze position are shown in Fig. 4. Gaze is defined as the absolute position of the eyes in space, and it is obtained by adding eye rotation in the orbit and head rotation in space. Eye movements present the typical nystagmic pattern made by fast movements (*saccade*) in the same direction as head rotation and slow compensating movements (*slow phase*) in the opposite direction as during passive head rotation in darkness [6].



(a)

(b)

Fig. 3. Head angular velocity signals from simultaneous recordings by (a) a standard potentiometer system and (b) by the gyro (derivative of potentiometer position signal).

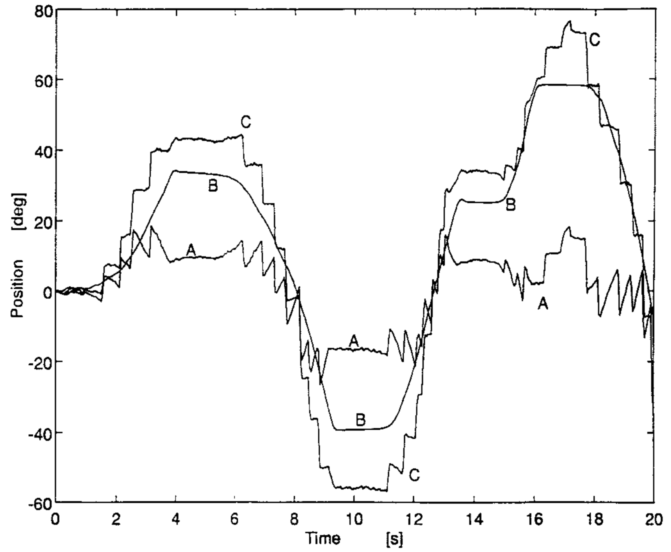


Fig. 4. An example of eye–head coordination during active head rotation in darkness. Eye position A has been recorded with electrooculography. Head position B has been recorded by means of the gyro and the gaze C has been obtained via software as sum of A and B.

V. CONCLUSION

It has been demonstrated that the FOG can be conveniently used for recording head rotations. FOG performances, in terms of low-noise and subject comfort, seem to suggest that it represents a useful device for the evaluation of VOR during active head rotations. Its simplicity makes the system eligible also for use in critical testing conditions like microgravity.

REFERENCES

[1] R. Schmid and D. Zambarbieri, "Eye-head coordination during active and passive head rotation in the dark," in *The Head-Neck Sensory Motor System*, A. Berthoz, W. Graf, and P. P. Vidal, Eds. New York: Oxford Univ. Press, 1992, pp. 434–438.

[2] B. J. Thomson, Ed., "Selected papers on fiber optic gyroscopes," in *SPIE (Milestones Series)*, Bellingham, MA, 1989, vol. MS-8.

[3] H. Lefevre, *The Fiber-Optic Gyroscope.* Boston, MA: Artech House, 1993.

[4] Hitachi gyroscope model HOFG-CLA-A2.

[5] V. Annovazzi-Lodi and S. Donati, "An optoelectronic interconnection for bidirectional transmission of biological signals," *IEEE Trans. Biomed. Eng.*, vol. 35, pp. 595–606, Aug. 1988.

[6] R. Schmid and D. Zambarbieri, "Strategy of eye-head coordination," in *Oculomotor Control and Cognitive Processes.* R. Schmid and D. Zambarbieri, Eds. Amsterdam, The Netherlands: Elsevier, 1991, pp. 229–246.

S. Donati (M'75), photograph and biography not available at the time of publication.

V. Annovazzi-Lodi (M'89), photograph and biography not available at the time of publication.

L. Bottazzi, photograph and biography not available at the time of publication.

D. Zambarbieri (M'90), photograph and biography not available at the time of publication.