

Wearable Robots

BIOMECHATRONIC EXOSKELETONS

Edited by
JOSÉ L. PONS

 **WILEY**



Wearable Robots: Biomechatronic Exoskeletons

Edited by
José L. Pons

CSIC, Madrid, Spain



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John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01, Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 6045 Freemont Blvd, Mississauga, Ontario, L5R 4J3, Canada

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British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 978-0-470-51294-4 (HB)

Typeset in 9/11pt Times by Laserwords Private Limited, Chennai, India

Printed and bound in Great Britain by Antony Rowe Ltd, Chippenham, Wiltshire

This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

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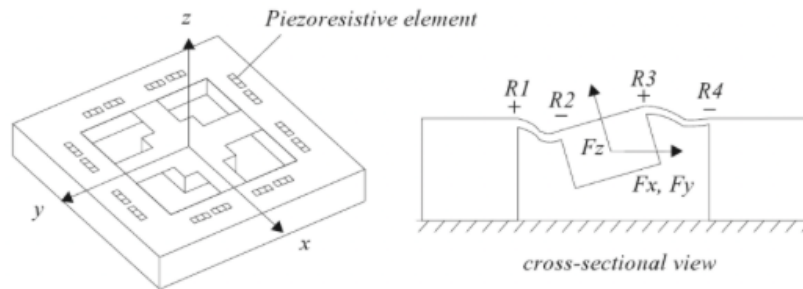


Figure 6.5 Accelerometer design for three-dimensional measurements. A full bridge circuit of piezoresistors detects unbalanced voltage. Reproduced from www.hitachimetals.com

of the mass is a measure of the difference between the acceleration $\mathbf{a}$ of the body and the acceleration $\mathbf{g}$ due to the earth's gravity acceleration, projected on to the sensitive axis of the sensor, which is represented by the unitary vector $\mathbf{n}$. The electrical output signal is represented by the magnitude of the vector $\mathbf{S}$, as

$$\mathbf{S}_{A,n} = k_{A,n}(\mathbf{a} - \mathbf{g}) \cdot \mathbf{n} + o_{A,n} \quad (6.1)$$

where $k_{A,n}$ represents a scale factor and $o_{A,n}$ the offset. A three-dimensional accelerometer can be produced by combining three accelerometers with orthogonal axes (see Figure 6.5). Three-dimensional configurations to measure body inclination are typically achieved with piezoresistive sensors. Other means of producing symmetrical capacitive triaxial accelerometers have also been proposed (Lotters, 1998).

Piezoelectric accelerometers are active devices that generate power under a mechanical excitation and are therefore not suitable for measurement of accelerations produced by static forces. Capacitive pendulous accelerometers typically respond to motion of the proof mass with a change of voltage across a capacitive sensor element. Capacitive accelerometers feature high sensitivities (in the range of 10 mV/g).

6.2.1.7 Gyroscope

Gyroscopes are rate sensors that commonly use vibrating mechanical elements (proof-mass) to sense rotation. Gyro technologies include mechanical, optical and vibrating types. The operation is typically based on the transfer of energy between two vibration modes of a structure, caused by Coriolis acceleration, which occurs in a rotating frame and is proportional to the rotational velocity. In MEMS vibrating gyroscopes, a comb structure is formed on the silicon substrate to detect Coriolis acceleration effects. When the sensor experiences a rotation about its sensitive axis (see Figure 6.6), the vibrating element experiences proportional Coriolis forces in a direction tangential to the rotation. The magnitude of this force is given by

$$f = 2m\mathbf{v}\omega \quad (6.2)$$

where m is the mass of the vibrating element, v the linear velocity of the element and ω the angular rate.

Analog Devices has been actively developing tuning fork-based designs for MEMS gyroscopes for several years. Fully integrated circuits (ICs) combining mechanical structures are being developed, containing signal processing circuitry for calibration and tuning. Measurement ranges of available MEMS gyroscopes go from 75 to 300°, with sensitivities that can range from 5 to 25 mV/degree s.

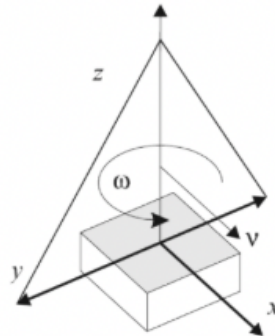


Figure 6.6 Operation of a vibrating gyroscope

Optical gyros are also available; these are based on the detection of phase differences in light waves travelling counter to the direction of rotation. Optical gyroscopes offer higher bias stabilities than vibrating gyroscopes but are more costly.

Recent advances in wireless technologies are being combined with MEMS inertial sensors to configure novel motion capture platforms (Brunetti *et al.*, 2006). In particular, accelerometers have been judged suitable for compensation of user motion, e.g. in closed-loop configurations for wearable vision platforms (Mayol, Tordoff and Murray, 2000) or tremor compensation in instruments for microsurgery (Riviere, Ang and Khosla, 2003). Examples of applications of rate gyroscopes include active compensation of upper limb tremor by means of motorized exoskeletons (Rocon *et al.*, 2005), control and monitoring of leg orthoses (Moreno *et al.*, 2006), neural vestibular prostheses (Liu *et al.*, 2003) and others. Case Study 6.5 describes a method of estimating limb orientation in exoskeleton devices by means of inertial sensors fusion.

6.2.2 Bioelectrical activity sensors

According to Malmivuo and Plonsey (1995), the human body can be modelled as a volume conductor since it is composed mainly of electrolytes and thus has some conductivity. In human cells there is a natural voltage difference between the inside and outside of the membrane. Depolarization of the motor unit causes depolarization of the muscle cell. This depolarization produces an electric impulse that travels through the volume conductor. The same operating principle can also be applied in the case of brain signals, where the impulses produced by depolarization of the neuron cells in the brain tissue travel through the volume conductor and can be measured on the scalp.

To record these electrical potentials, a set of electrode leads must be placed as close as possible to the sources. There are two main approaches: one using surface electrodes on the skin and another using internal electrodes placed near the active cells.

Amplification of these signals raises a number of issues, chiefly concerning safety and noise. In order to acquire the signals with a high signal-to-noise ratio, a better contact between the lead and the tissue is required. A better contact ensures less noise in the acquired signal, but on the other hand it entails a greater risk of electric shock in the event of failure of the power supply system, as the impedance contact between the user and the leads is relatively low. This risk is even higher in the case of implanted electrodes, where the leads are directly connected to the internal tissue.

The materials used for the electrodes are highly dependent on the type of contact, e.g. silver/silver chloride (Ag/AgCl) or stainless steel. These different materials present different electrical responses, which are determined by their electrical properties. The electrodes can be used on dry or wet contacts, or again they may be insulated. Insulated electrodes typically pose problems with the time constant