Wearable Inertial Sensors and Their Applications

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1. INTRODUCTION

Wearable inertial sensors are the most common wearable devices for the measurement of motion and physical activities associated with daily living.

The combination of an accelerometer and a gyroscopic sensor is particularly effective for evaluating motion, and their small size makes them easy to wear on various parts of the body.

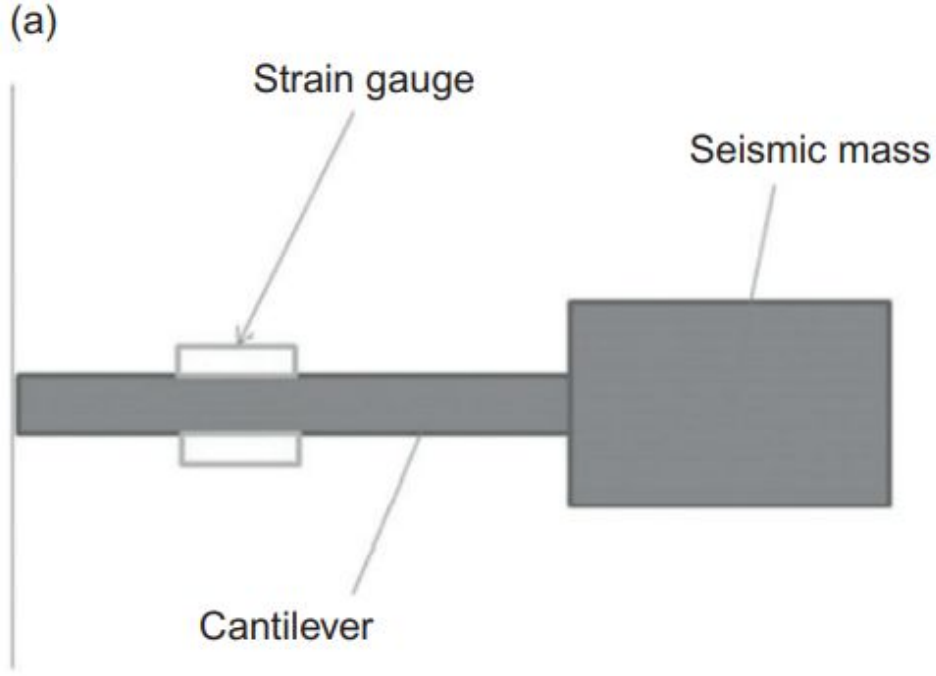
Type 1: Accelerometers

Acceleration can be derived from *the first derivative of the velocity or the second derivative of the displacement.* However, differentiation of the signal usually increases noise. Thus, direct measurement of acceleration is often easier and more convenient. Example: Capacitive Accelerometer measure the Change in the capacitance more accurately.

Many types of accelerometers with different specifications are commercially available. For example, accelerometers are <u>*relatively cheap and reliable for use as shock sensors in automobiles.*</u> Novel iMEMS technology is used to produce small and sensitive accelerometers. Overall, the correct type of accelerometer must be selected for each specific application. Romberg's tests is used to measure Acceleration.

Type 2:Beam-type accelerometers

Beam-type accelerometers are the most sensitive in the *body motion acceleration range*. In a beam-type accelerometer, an elastic beam is fixed to a base at one end, and a mass, called the seismic mass, is attached to the other end. Rapid stepping tests is done by Motor coordination tests.

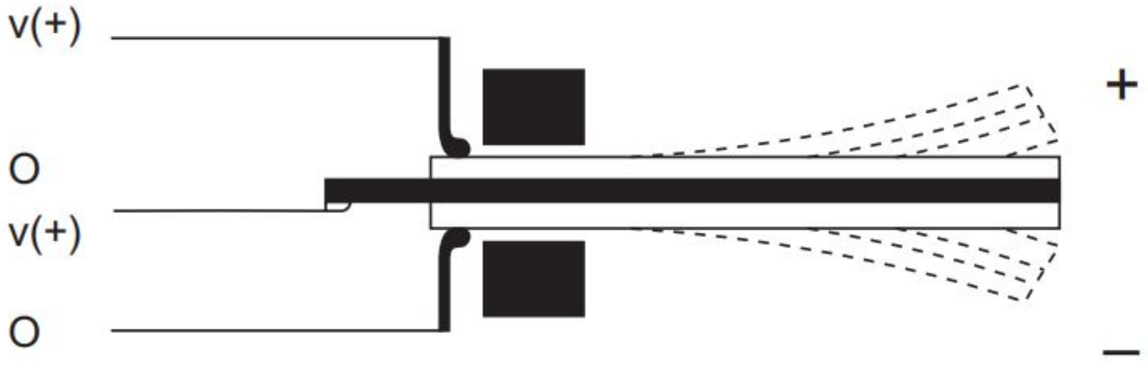


Type 3: Piezoelectric accelerometers

Piezoelectric accelerometers are commonly used when only the *time-varying components of acceleration require measurement*.

Advantages: Extremely low power consumption, simple detection circuits, high sensitivity, and inherent temperature stability characterize piezoelectric accelerometers.

The highest quality commercial accelerometers are constructed using a *piezoelectric crystal.*Pizeoresistive Accelerometer uses *piezoresistive* substrate.



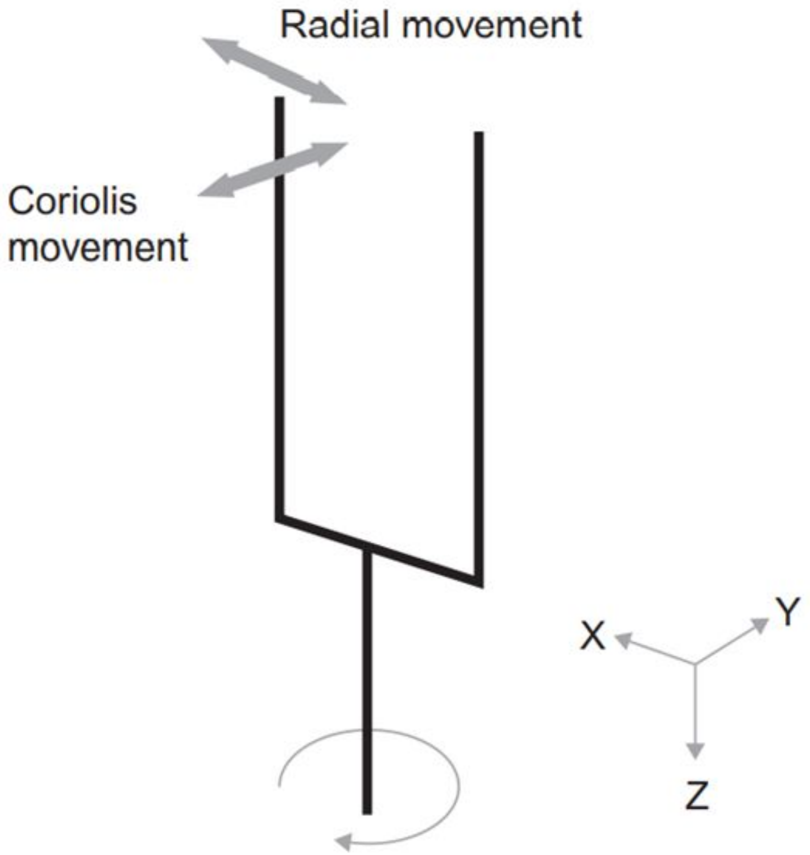
Type 4: Gyroscopic Sensors

Angular velocity can be measured with a gyroscope, which consists of a spinning wheel mounted on a movable frame. When the wheel is spinning, it tends to retain its initial orientation in space, regardless of the central forces applied to it.

Typically, micromachined gyroscopes are specialized vibrating accelerometers that measure Coriolis forces.

A tuning fork directly detects the *angular velocity in a vibratory gyroscopic sensor.* The tines of the tuning fork are piezoelectrically excited perpendicular to the wafer surface.

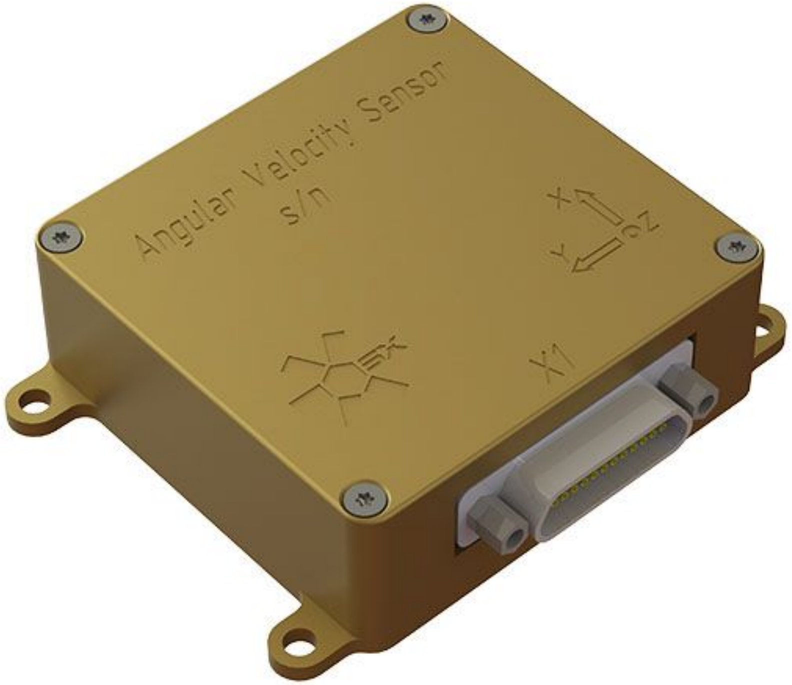
Gyroscopic Sensors



Type 5: An angular velocity sensor

An angular velocity sensor with two or three axes is also possible.

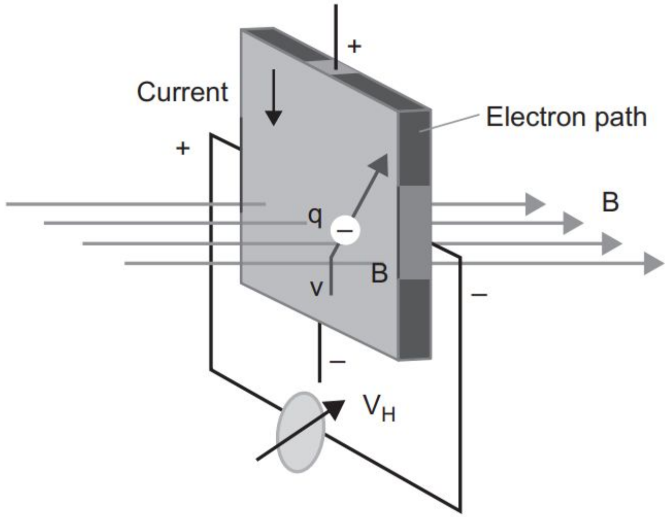
The triaxial micro-angular velocity sensor is mainly fabricated by the silicon-on-insulator (SOI) technique, and it operates to detect the three-axes angular velocities



Type 6:Magnetic Sensors

The Hall Effect

Magnetic sensors, which are available with different sensitivities, are used for precise measurements of body movement. Common magnetic sensors are based on the Hall effect, which generates magnetic impedance and magnetic resistance as a result of the interaction between moving electronic carriers and an external magnetic field. In metals, these carriers are electrons.



Type 6.1:Magnetoimpedance Sensors

Magnetoimpedance sensors are based on the magnetoimpedance (MI) effect in amorphous wires and are typically fabricated with complementary metal-oxide-semiconductor (CMOS) multi-vibrator integrated circuitry [3,4].

Amorphous materials are non-crystalline; they have a uniform internal structure and typically exhibit ideal soft magnetic properties.

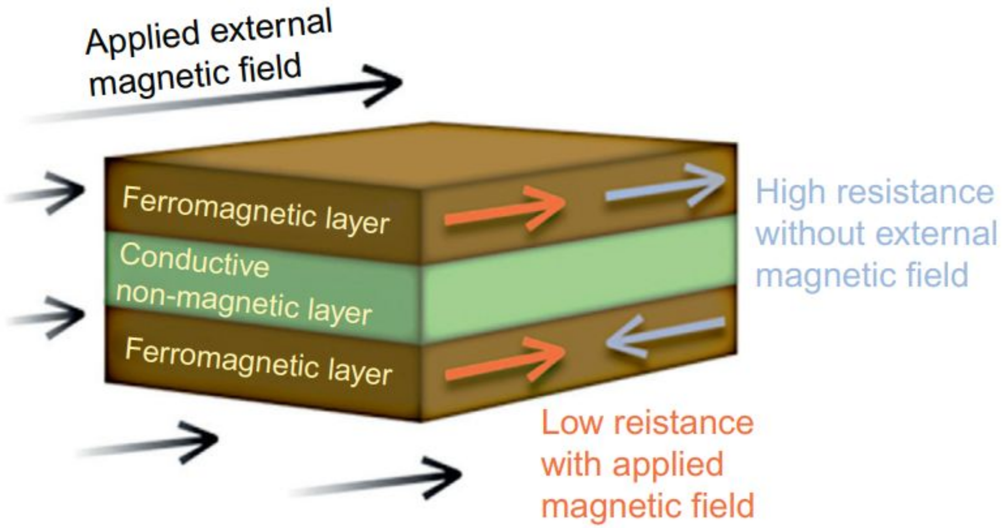
Type 6.2:Magnetoresistance Sensors

When a perpendicular magnetic field is applied to a classical semiconductor, such as an InSb(Indium Antimonide) plate surface, the resistance increases.

This effect is magnetoresistance (MR), and it depends on the electron mobility of the material.

Type 6.3:Giant Magnetoresistance Sensors

The electric current in a magnetic multilayer consisting of a sequence of thin magnetic layers separated by equally thin non-magnetic metallic layers is strongly influenced by the relative orientation of the magnetizations of the magnetic layers. The cause of this large resistance variation, also called giant magnetoresistance (GMR), is attributed to the scattering of the electrons at the layer interfaces.



OBTAINED PARAMETERS FROM INERTIA SENSORS

Parameters	Signals
Velocity	Triaxial acceleration
Number of steps	Triaxial acceleration
Number of strides	Triaxial acceleration
Time	Triaxial acceleration
Average stride time	Triaxial acceleration
Average stride time	Triaxial acceleration
Cadence	Triaxial acceleration
Root mean square (RMS) values	Triaxial acceleration, triaxial gyroscopic velocity, triaxial magnetic field
Regularity of steps	Triaxial acceleration
Regularity of strides	Triaxial acceleration
Angle	Combined with triaxial acceleration, triaxial angular velocity, and triaxial magnetic field

APPLICATIONS FOR WEARABLE MOTION SENSORS

The use of acceleration signals was discussed as early as the late 1980s.

Acceleration signals at the lower back, which is close to the center of gravity in a typical human, we monitored, and different signals were obtained for patients with various diseases.

With the development of *integrated circuit (IC) technology, the cost of accelerometers, gyroscopes, and magnetic sensors has greatly reduced, and these instruments have been used in several rehabilitation studies.*

Rapid stepping tests - Motor coordination tests

iMEMS - Accelerometer

Capacitive Accelerometer - Change in the capacitance

Fall Risk Assessment with Rehabilitation Battery

Various tools for assessment of subjective and objective falling risk have been developed.

Subjective methods, such as diaries, questionnaires, and surveys, are inexpensive; however, these tools depend on the experience of therapists and caregivers, individual observation, and subjective interpretation, all of which lead to inconsistency in assessment results.

Fall Detection

Falls and fall-induced injuries are major public-health problems among elderly individuals.

Many methods and programs to prevent fall injuries already exist, including regular exercise, vitamin D and calcium supplementation, the withdrawal of psychotropic medication, environmental hazards assessment and modification, hip protectors, and multifactorial preventive programs for the simultaneous assessment and reduction of many of the predisposing and situational risk factors.

Clinical Assessment for Parkinson's Disease

Inertial sensors have also been applied to patients with various gait abnormalities, including the dyskinesia associated with Parkinson's disease (PD).

The use of a sensor based system to monitor PD is promising for improvement of the clinical management of PD patients. A portable triaxial accelerometer attached at the shoulder was used to monitor the severity of the dyskinesia, which occurs as an uncomfortable side effect of PD medication.

Quantitative Evaluation of Hemiplegic Patients

Hemiparesis, or unilateral paresis, is weakness of one entire side of the body (hemi- means "half"). Hemiplegia is, in its most severe form, complete paralysis of half of the body.

A semi-quantitative score based on a physical therapist’s observation is used as a standard for evaluation of hemiplegic patients. Hemiplegic legs and arms are observed and scored from 1 to 6 on the Bronstrom scale [56].

The physical therapist scores the patient’s performance while walking or executing upper-arm movements.

Energy Expenditure

Current accelerometers can estimate *the energy expenditure associated with physical activity*. Over the past several decades, the integral of the acceleration signal per unit time has been assumed to be proportional to the oxygen consumption [66,67].

A small portable accelerometer was developed to estimate the energy expenditure of daily activities.

WEARABLE INERTIAL SENSOR APPLICATIONS IN CLINICAL PRACTICE AND FUTURE RESEARCH DIRECTIONS

Wearable inertial sensors with appropriate specifications have been used in ***clinical applications***. The *critical issue for successful clinical use of wearable inertial sensors is sensor selection, which must be considered on a case-by-case basis.*

Acceleration, angular velocity, and magnetic sensors with a maximum nine-degrees-of-freedom are commercially available.

Higher accuracy is not necessarily required for rehabilitation purposes. In clinical settings*, simple signal interpretation is required for both physicians and patients.* For more widespread popularization of wearable inertial sensors in clinical practice, development of *improved evidenced-based interpretation is proposed.*