Inductive Plethysmography

The inductive plethysmography method for breathing monitoring consists of two elastic conductive wires placed around the thorax and the abdomen to detect the cross sectional area changes of the rib cage and the abdomen region during the respiratory cycles. The conductive wires are insulated and generally sewn in a zig-zag fashion onto each separate cloth band. They can be considered as a coil and are used to modulate the output frequency of a sinewave current produced by an electric oscillator circuit. As a matter of fact, the sinewave current generates a magnetic field, and the cross-sectional area changes due to the respiratory movements of the rib cage and of the abdomen determine a variation of the magnetic field flow through the coils. This change in flow causes a variation of the self-inductance of each coil that modulates the output frequency of the sinusoidal oscillator. This relationship allows for monitoring the respiratory activity by detecting the frequency change in the oscillator output signal. For accurate volumetric measurements using RIP, it is assumed that the cross-sectional area within the rib cage and the abdomen coil, respectively, reflects all of the changes occurring within the respective lung compartment, and further that the lung volume change is the sum of the volume changes of the two compartments. Under optimal situations, lung volume can be approximated with an error less than 10%.

Impedance Plethysmography

This technique consists of injecting a high frequency and low amplitude current through a pair of electrodes placed on the thorax and measuring the trans-thoracic electrical impedance changes [40]. As a matter of fact, there is a relationship between the flow of air through the lungs and the impedance change of the thorax. The measurements can be carried out by using either two or four electrode configurations. Electrodes can be made of fabric and integrated into a garment or,even, embedded into an undershirt. It is worthwhile noting that by measuring the trans-thoracic electrical impedance it is possible to non-invasively monitor, in addition to breathing rate also tidal volume, functional residual capacity, lung water and cardiac output.

Pneumography Based on Piezoresistive Sensor

Piezoresistive pneumography is carried out by means of piezoresistive sensors that monitor the cross-sectional variations of the rib cage. The piezoresistive sensor changes its electrical resistance if stretched or shortened and is sensitive to the thoracic circumference variations that occur during respiration. Piezoresistive sensors can be easily realized as simple elastic wires or by means of an innovative sensorized textile technology. It consists of a conductive mixture directly spread over the fabric. The lightness and the adherence of the fabric make the sensorized garments truly unobtrusive and uncumbersome, and hence comfortable for the subject wearing them. This mixture does not change the mechanical properties of the fabric and maintains the wearability of the garment. Figure 1.3 shows where the two conductive wires or bands could be applied.

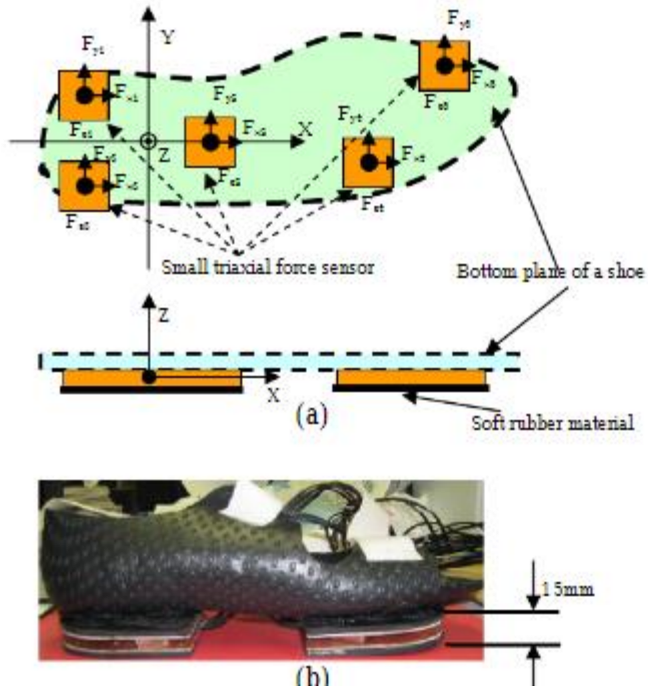
Plethysmography Based on Piezoelectric Sensor

This method is based on a piezoelectric cable or strip which can be simply fastened around the thorax, thus monitoring the thorax circumference variations during the respiratory activity. A possible implementation can be a coaxial cable whose dielectric is a piezoelectric polymer (p(VDF-TrFE)), which can be easily sewn in a textile belt and placed around the chest. The sensor is sensitive to the thorax movements and produces a signal directly proportional to the thorax expansion in terms of charge variation, which was converted in an output voltage proportional to the charge by means of a charge amplifier. A suitable local processor can enable implementation of the Fast FourierTransform in real time and extraction of the breathing rate.

Wearable GRF Sensor System

The quantitative analysis of gait variability using kinematics and kinetic characterizations can be helpful to medical doctors in monitoring patients' recovery status in clinical applications. Moreover, these quantitative results may help to strengthen their confidence in the rehabilitation. Walking speed, stride length, the centre of mass (CoM) and the centre of pressure (CoP) have been considered as factors in the evaluation of walking gait. According to one study on slip type falls, friction force was used to draw up important safety criteria for detecting safe gait, so the transverse components of ground reaction force (GRF) may provide important information for quantifying gait variability. Many kinds of stationary systems such as force plates and instrumented treadmill devices are available to measure CoP and triaxial GRF. Because a stationary force plate cannot measure more than one stride, in studies of continuous walking, a complex system consisting of many force plates and a data fusion method must be constructed . Therefore, the force plate technology probably imposes some constraints on our ability to measure human movement and is not feasible for measurements in everyday situations. An instrumented treadmill or dynamometric platform formed by laying two force plates under a treadmill can overcome some limitations of the system with distributed multiple force plates in successive measurements of the GRF for gait evaluation. However, a guide used to constrain the direction of the foot is necessary to ensure that subjects walk along a straight line, because if a human body segment motion analysis system is not available for a simultaneous measurement of the foot orientation, any technique based on force plates conventionally requires subjects to walk along a pre-defined specific path. Although gait variability can be assessed in straight walking , gait analysis concentrating solely on straight-line walking or running may not adequately interpret gait variability, because turning or walking direction changes probably have effects on extrinsic gait variability . To overcome such limitations of stationary devices in GRF measurement, many researchers are developing wearable sensors attached to shoes . Pressure sensors have been widely used to measure gaits and the distributed vertical component of GRF and to analyze the loading pattern on the plantar soft tissue during the stance phase of gait , but in these systems the transverse components of GRF (friction forces) which are one of the main factors leading to falling, have been neglected. By fixing two externally mounted sensors beneath the front and rear boards of a special shoe, researchers have developed an instrumented shoe for ambulatory measurements of CoP and triaxial GRF in successive walking trials, and the application of the instrumented shoe to estimate joint moments and powers of the ankle was introduced in. The mounted sensor itself, having a height of 15.7 mm, increases the height and weight of the shoe, and affects normal walking gait. Moreover, its application study was restricted to human kinetics analysis using the spatio temporal measurements of GRF and CoP.

A wearable GRF sensor system was constructed using five small triaxial force
sensors (USL06-H5-500N-C, weight: 15 g, size: 20 mm × 20 mm × 5 mm). The GRF and CoP measured using the wearable sensor system were expressed in a global coordinate system which was located on the interface between the instrumented shoe and the ground. The origin of the global coordinate system was fixed to a point around the anatomical centre of the ankle when the sensor system was worn on the foot. The x-axis was chosen to represent the anterior-posterior direction on the interface plane contacting with the floor, which was based on landmarks from the shoe. The z-axis was made vertical, and the y-axis was chosen such that the resulting global coordinate system would be right-handed. By mounting the five triaxial sensors on an aluminum plate beneath the shoe, we can accurately align all five local coordinate systems defined for each triaxial sensor with the global coordinates. Fxi, Fyiand Fzi (I = 1, 2, 3, 4 and 5) indicate triaxial forces measured by the distributed five triaxial sensors, and (xi, yi) is defined as the position of each triaxial sensor, for example, (x5, y5) indicates the position of the sensor placed on the forefoot. The total weight of the sensor shoe is about 300 g, and the shoe size is 250 mm.


Y
X
Z
Small triaxial force sensor
Bottom plane of a shoe
Soft rubber material
(a)
15mm
(b)