ELECTRONIC SENSOR TECHNOLOGIES FOR WOUNDS

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INTRODUCTION

This document is part of the Patient@home track, related to the "diabetic foot ulcer" area.

This document lists sensor technologies that can be used for monitoring, diagnosis and treatment of wounds. The focus is primarily on measuring wounds at home; however, it will be extended to cover the scenarios of BEFORE, DURING and AFTER hospitalization eventually.

This is a working document, to be supplied during the work phase when more sensors and/or wound applications and knowledge become available.

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The need, from OUH

In WP1.2 we will develop novel, and improve existing sensory devices for monitoring the healing process of diabetic foot ulcers, which are one of the most common and serious issues for diabetic patients, as it often precedes a lower leg amputation which reduces the independence of the patient.

Anticipated measurements will be, for instance, measurements of pH, exudation (sweating), oxygen tension, blood flow, bacterial products, pressure conditions and skin temperature.

Here, we plan sensory devices that require the cooperation of the patient; for example by using dedicated pH sensors for the ulcer base and surroundings, or electrodes for measuring secretion and oxygen tension.

Electronic sensors

- An electronic sensor is a device that senses a condition and typically transforms the sensed parameter into a current or voltage.
- A sensor gathers information passively. There are many different and specialized sensors, but most measure some of the following fundamental parameters:

- Time
- Pressure
- Temperature
- Light
- Magnetic field
- Position, distance, speed, acceleration
- Orientation, roll, pitch, yaw
- Voltage, current, resistance, inductance and capacitance.
- Sound
- Pictures
- Chemicals

Wound sensor measurements of interest

Some parameters relevant for wounds could be:

Temperature
Color
Humidity
Conductivity
Mechanical impedance
Movement
Concentration of chemicals, pH, Oxygen …

The listed potential measurements are open to improvement…

How sensor measurements are used

A sensor provides some data; for instance, the temperature at a defined point over time.

This only becomes useful information when it is coupled with the state of, say, a wound. It can then be used to monitor the development (healing process) of the wound. So the sensor data must be mapped using medical knowledge of wounds in order to produce meaningful information.

Sometimes the mapping can only be done by experts in the field taking different measurements into account, but it is also possible that the mapping can be formalized and put into the sensor (normally a sensor is associated with a microprocessor capable of data collection and suitable calculations on the data). In such a case the output of the sensor could be a warning or an alarm, if, for instance, the temperature was outside a predefined range.

It is also conceivable to use sensor measurements to administer treatments. If, in our example, the temperature were too low, we could imagine using some actuators that could stimulate blood flow or otherwise increase the temperature in the wound.

The sensor could be **direct** (i.e. we would measure the temperature directly with a sensor in the wound) or **indirect** (measured at a distance using thermography). The sensor could be small and light, and worn by the patient; or more comprehensive, and used regularly either by the patient, the doctor, or a nurse. The sensor might not be transportable and only available at the practitioner's office, or at a hospital. An example of the latter is an X-ray or MR-scanner.

How actuators are used

An **actuator** is a mechanical device that converts energy into motion.

It would be very interesting if actuators could be used directly in the healing process – for instance by somehow (electrical / mechanical / heating?) stimulating blood flow into the wound area. This becomes more powerful when combined with sensors and algorithms encapsulating medical knowledge.

Possible wound states

Several parameters can be used to characterize the state of a wound:

Secrete flow
Colonization of different bacteria
Surface temperature of the wound
Wetting (of bandage)

The above list is just a place holder; it should be expanded by wound experts.

From sensor measurements→to wound state

Temperature
Resistance
Conductivity
Color
Luminance
Movement
Optical
Sound
etc.

Amount of secretion
Colonization of different bacteria
Healing process of the wound
Bleeding through
etc.

Sensor measurements

In the following sections the different sensor principles will be further elaborated on.

TOPIC	
Temperature	-
Pressure	-
Humidity	-
Light	-
Magnetic	-
Position and orientation	-
Fundamental electrical measurements	-
MEMS	-

TEMPERATURE SENSORS FOR WOUNDS

INTRODUCTION

Temperature measurements have a low sampling rate, mainly due to the thermal time constants involved in most thermometers and thermo-sensors. In a wound, the relative temperature compared to surrounding tissue might be of importance. Temperature measurements are done with a probe, so in order to measure the temperature in a wound, thermal contact with the wound is in many cases essential.

Alternatively, temperature can be measured via the thermal resistance between the point where we want to measure the wound temperature and the probe. The obtained reading depends on the thermal resistance in the measuring point and the thermal resistance to the rest of the probe surroundings (and the corresponding temperatures). If the thermal resistances involved are not controlled properly, the temperatures measured can exhibit severe errors.

There are many different sensors available for measuring temperature. This is not surprising since many material parameters change with temperature. There are two fundamentally different types of temperature sensors:

- *Contact sensors*
- *Noncontact sensors*

Principles; contact temp. sensors

Contact temperature sensors measure their own temperature.

One infers the temperature of the object with which the sensor is in contact, by assuming or knowing that the two are in thermal equilibrium (i.e. there is no heat flow between them).

Types of Contact Temperature Sensors [1]:

- Thermocouples (TCs)
- Thermistors
- Resistance Thermometers (RTDs, PRTs, SPRTs)
- Liquid in Glass Thermometers (LIGs)
- Filled System Thermometers (Filled)
- Bimetallic Thermometers (Bimetals)
- Semiconductor Temperature Sensors (Semi, ICs)
- Labels, Crayons, Paints, Tabs (Phase Change Devices)

Principles; noncontact temp. sensors

Most commercial and scientific noncontact temperature sensors measure the thermal radiant power of the Infrared or Optical radiation that they receive from a known or calculated area on their surface, or a known or calculated volume within them (in those cases where the object is semi-transparent within the measuring wavelength pass band of the sensor).

The most common infrared thermometers are [2]:

Spot Infrared Thermometer or Infrared Pyrometer, which measures the temperature at a spot on a surface;
Infrared Scanning Systems, which scan a larger area, typically by using what is essentially a spot thermometer pointed at a rotating mirror; and
Infrared Thermal Imaging Cameras or Infrared Cameras, which are essentially infrared radiation thermometers that measure the temperature at many points over a relatively large area to generate a two-dimensional image (thermogram), with each pixel representing a temperature.

The IR based temperature sensors could potentially provide the capability to measure the temperature several times per second – much faster than other temperature sensors.

IR measurements in wounds

"Application of infrared thermography for early assessment of burn wound depth in children- a preliminary study" [3].

The change of skin temperature in a deep burn wound due to the damage in the blood microcirculation can exceed even 3.8 K with respect to healthy skin.

PRESSURE SENSORS FOR WOUNDS

INTRODUCTION

Pressure is a fundamental measurement. Here we consider how to measure pressure in wounds.

A pressure sensor measures pressure, typically of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and it is usually stated in terms of force per unit area. A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed.

In wounds the most relevant measure of pressure would be from a potential bandage, or from the environment (e.g. clothes or lying in bed) [4].

Principles; pressure sensors

- Absolute pressure sensor; measures the pressure relative to perfect vacuum.
- Gauge pressure sensor, measures pressure relative to atmospheric pressure.
- Vacuum pressure sensor; measures pressures below atmospheric pressure, showing the difference between that low pressure and atmospheric pressure.
- Differential pressure sensor; measures the difference between two pressures, one connected to each side of the sensor. Technically speaking, most pressure sensors are really differential pressure sensors; for example a gauge pressure sensor is merely a differential pressure sensor in which one side is open to the ambient atmosphere.

Sealed pressure sensor; measures pressure relative to some fixed pressure rather than the ambient atmospheric pressure (which varies according to the location and the weather). [4]

Types of electronic pressure sensors

Electronic pressure sensors generally use a force collector (such a diaphragm, piston, bourdon tube, or bellows) to measure strain (or deflection) due to applied force (pressure) over an area.

- Piezo-resistive strain gauge. Uses the piezoresistive effect of bonded or formed strain gauges to detect strain due to applied pressure. Common technology types are Silicon (Monocrystalline), Polysilicon Thin Film, Bonded Metal Foil, Thick Film, and Sputtered Thin Film. Generally, the strain gauges are connected to form a Wheatstone bridge circuit to maximize the output of the sensor. This is the most commonly employed sensing technology for general purpose pressure measurement. Generally, these technologies are suited to measure absolute, gauge, vacuum, and differential pressures.
- Capacitive. Uses a diaphragm and pressure cavity to create a variable capacitor to detect strain due to applied pressure. Common technologies use metal, ceramic, and silicon diaphragms. Generally, these technologies are most applied to low pressures (Absolute, Differential and Gauge).
- Electromagnetic. Measures the displacement of a diaphragm by means of changes in inductance (reluctance), LVDT, Hall Effect, or by eddy current principle.
- Piezo-electric. Uses the piezoelectric effect in certain materials such as quartz to measure the strain upon the sensing mechanism due to pressure. This technology is commonly employed for the measurement of highly dynamic pressures.
- Optical. Techniques include the use of the physical change of an optical fiber to detect strain due to applied pressure. A common example of this type utilizes Fiber Bragg Gratings. This technology is employed in challenging applications where the measurement may be highly remote, under high

temperature, or may benefit from technologies inherently immune to electromagnetic interference. Another analogous technique utilizes an elastic film constructed in layers that can change reflected wavelengths according to the applied pressure (strain).
- Potentiometric. Uses the motion of a wiper along a resistive mechanism to detect the strain caused by applied pressure. Other types of electronic pressure sensors use other properties (such as density) to infer pressure of a gas, or liquid.
- Resonant. Uses the changes in resonant frequency in a sensing mechanism to measure stress, or changes in gas density, caused by applied pressure. This technology may be used in conjunction with a force collector, such as those in the category above. Alternatively, resonant technology may be employed by expose the resonating element itself to the media, whereby the resonant frequency is dependent upon the density of the media. Sensors have been made out of vibrating wire, vibrating cylinders, quartz, and silicon MEMS. Generally, this technology is considered to provide very stable readings over time.
- Thermal. Uses the changes in thermal conductivity of a gas due to density changes to measure pressure. A common example of this type is the Pirani gauge.
- Ionization. Measures the flow of charged gas particles (ions) which varies due to density changes to measure pressure. Common examples are the Hot and Cold Cathode gauges.
- Others. There are numerous other ways to derive pressure from its density (speed of sound, mass, index of refraction) among others. [4]

Tactile sensors

The term tactile sensor usually refers to a transducer that is sensitive to touch, force, or pressure. Tactile sensors are employed wherever interactions between a contact surface and the environment are to be measured and registered [5].

A sensor's sensitivity indicates how much the sensor's output changes when the measured quantity changes. The term tactile refers to the somatosensory system or more commonly the sense of touch. A tactile sensor is a device which receives and responds to a signal or stimulus having to do with force.

Tactile sensors are generally known and can be grouped into a number of different types depending upon their construction; the most common groups are [6]:

- Piezo-resistive
- Piezo-electric
- Capacitive
- Elasto resistive sensors

Ideally tactile sensors combine force sensing, vibration sensing, and heat transfer sensing.

Pressure Sensor Arrays

Pressure sensor arrays are large grids of tactels. Each tactel is capable of detecting normal forces. The advantage of tactel based sensors is that they provide a high resolution ‘image’ of the contact surface.

Pressure sensor arrays are often available in thin-film form.

Examples of such sensors include arrays built from:

- Conductive rubber [8]
- Lead zirconate titanate (PZT) [9]
- Polyvinylidene fluoride(PVDF) [9]
- PVDF-TrFE [9]
- FETs [10]
- Metallic capacitive sensing elements [7]

Pressure sensor for wounds

It is assumed that the pressure inside bandages is of importance. The pressure could be read by many types of pressure sensors.

Imagine using a fiber optic Bragg sensor, which is woven into a layer of the bandage. The advantage is that such a sensor can have several measurement points for both temperature and strain along the fiber. Since the measurement equipment includes lasers and electronics, it is conceivable that the fiber is only connected and measured when the patient visits the practitioner.

HUMIDITY SENSORS FOR WOUNDS

INTRODUCTION

A hygrometer is an instrument used for measuring the moisture content in the environment. Humidity measurement instruments usually rely on measurements of some other quantity such as temperature, pressure, mass or a mechanical or electrical change in a substance as moisture is absorbed. By calibration and calculation, these measured quantities can lead to a measurement of humidity.

Modern electronic devices use temperature of condensation, or changes in electrical capacitance or resistance to measure humidity changes.

Principles of humidity sensors

Dew point is the temperature at which a sample of moist air (or any other water vapor) at constant pressure reaches water vapor saturation. At this saturation temperature, further cooling results in condensation of water.

- Chilled mirror dew point hygrometers. Uses chilled mirror and optoelectronic mechanism to detect condensation on the mirror surface. An accuracy of 0.2 °C is attainable, which correlates at typical office environments to a relative humidity accuracy of about ±0.5%.
- Capacitive humidity sensors. The effect of humidity on the dielectric constant of a polymer or metal oxide material is measured. With calibration, these sensors have an accuracy of ±2% RH in the range 5–95% RH.
- Resistive humidity sensors. The change in electrical resistance of a material due to humidity is measured. Typical materials are salts and conductive polymers. Resistive sensors are less sensitive than capacitive sensors - the change in material properties is less, so they require more complex circuitry.
- The material properties also tend to depend both on humidity and temperature, which means in practice that the sensor must be combined with a temperature sensor. Robust, condensation-resistant sensors exist with an accuracy of up to ±3% RH.
- Thermal conductivity humidity sensors. The change in thermal conductivity of air due to humidity is measured. These sensors measure absolute humidity rather than relative humidity [11].

Wetting

Wetting of a bandage can be detected using a humidity sensor. If we consider embedding two conductive, electrically separated nets in the bandage, then we can use a resistance measurement to indicate wetting.

Humidity sensor arrays

It appears that no system involving arrays of electronic humidity sensors is currently available.

Determining humidity in close proximity to the wound could be of interest.

Imagine a modification of a Dew point hygrometer, where the mirror is shaped to follow the contours of the body part. Assume the mirror is chilled so condensation just occurs. The mirror is then placed close to the wound and the pattern of condensation is recorded (video) together with the temperature of the mirror.

Since we have condensation, the mirror could be replaced with an array of capacitive or conductive humidity sensors and thermometers.

In this way an image of the humidity profile across the wound could be provided.

LIGHT SENSORS FOR WOUNDS

Introduction

Photo sensors or photo detectors are sensors of light or other electromagnetic energy.

Active pixel sensors are image sensors consisting of an integrated circuit that contains an array of pixel sensors, each pixel containing a both a light sensor and an active amplifier.

Light measurements are derived measurements, depending on the existence of a light source, as most objects do not emit light.

The exception here is infrared radiation (IR) and fluorescence.

Some organic materials exhibit fluorescence; when illuminated with light at one wavelength, they emit light of a longer wavelength. The wavelengths and decay pattern are characteristic of the material.

Photo Sensors

There are many types of active pixel sensors commonly used in cell phone cameras, web cameras, and DSLRs. An image sensor produced by a CMOS process is also known as a CMOS sensor, and has emerged as an alternative to Charge-coupled device (CCD) sensors.

LEDs can be reverse-biased to act as photodiodes.

Optical detectors are mostly quantum devices in which an individual photon produces a discrete effect. Optical detectors that are effectively thermo-meters, responding purely to the heating effect of the incoming radiation, such as pyroelectric detectors, Golay cells, thermocouples and thermistors, but the latter two are much less sensitive.

Photo-resistors, or Light Dependent Resistors (LDR), changes resistance according to light intensity. Normally the resistance of Photo-resistor (LDR) decreases with increasing intensity of light falling on it.

Photovoltaic cells or solar cells which produce a voltage and supply an electric current when illuminated.

Photodiodes operate in photovoltaic mode or photoconductive mode.

Photomultiplier tubes containing a photocathode emits electrons when illuminated, the electrons are then amplified by a chain of dynodes.

Phototubes containing a photocathode which emits electrons when illuminated, such that the tube conducts a current proportional to the light intensity.

Phototransistors act like amplifying photodiodes.

Quantum dot photoconductors, or photodiodes, can handle wavelengths in the visible and infrared spectral regions. [12]

Hyperspectral Imaging

Hyperspectral imaging, like other spectral imaging, collects and processes information from across the electromagnetic spectrum. Much as the human eye sees visible light in three bands (red, green, and blue), spectral imaging divides the spectrum into many more bands. This technique of dividing images into bands can be extended beyond the visible.

DELTA Optics has developed variable optical filters, where each part of the filter only let light of a certain frequency pass. Such a filter could be used to record say 1000 images at different frequencies over the visible spectrum. These images contains much more information, compared to normal imaging using 3 filters (RGB).

Digital Cameras

Digital cameras can provide electronic images of very high quality.

Video cameras can take series of images in sequence, typically 30 images / second.

Due to the nature of perception by the human eye the individual images can often be of much lower quality without being objected to.

Resent developments in Digital Single Lens Reflex, DSLR, cameras provides high quality video - also for the individual image.

Digital cameras are readily available for instance in mobile phones.

The quality of the images depends on the:

- Light available
- Light sensor
- Lens, geometrical distortion, vignetting, chromatic aberration, flare.
- Movement of camera or subject.
- Focus, aperture and shutter speed.
- A/D converters
- Signal processing, e.g. Compression and white balance.

The light sensors are sensitive beyond the visible frequency range.

So for a response, which matches the human eye, filters must be used. Also the spectrum is typically broken down in 3 color ranges: Red, Green and Blue (RGB).

Most light sensors uses a pattern of color filtering applied to the single pixels, so one pixel is sensitive to red, and other pixels to blue and green respectively. The most common pattern is Bayer's, where one line of pixels are sensitive to green and red alternating and the neighbor line is sensitive to blue and green alternating.

Apart from the filters for each pixel the sensors are also fitted with micro lens, in order to capture as much light as possible.

Foveon has another approach; here the sensor is stacked in 3 layers with color filters in between, this gives better color resolution.

How can digital cameras be used for wounds?

- Document the healing process, and possibly take corrective actions if the healing is not progressing as expected. Since electronic images can easily be transmitted all over the world, medical experts does not necessary have to be close to the patient. What can be deduced from the images depends on the image quality.
- 3D images, allows stereoscopic view. A few cameras exists, for instance from Fuji. The use pattern is the same as above.
- 2D, Size and area, based on color boundaries. For best results the illumination and color response should be controlled. The geometrical distortion should be corrected and the distance should be known, as well as the orientation of the camera, e.g. the camera should be normal to the wound.
- Other possibilities arise by developing special cameras, where multiple images from different known positions are used, either by more exposures, more cameras or mirror mechanisms. This could be achieved relatively cheap by calibrating a 3D camera.
- 3D maps, Size, area, volume. The requirements are as above, but more exposures will be required, if the wound is complex.

The advantage of using digital cameras is they are readily available, but needs improvement if quality measurements should be required. Other possibilities involve scanning, either by moving a laser or by projecting suitable patterns.

So instead of using two cameras for 2 and 3D measurements one camera and one projector could be used.

An advantage of using a projector is that we have a relatively constant light source, which will facilitate comparison of pictures taken over time, - if using the same equipment. The measurements of 2 and 3D will require controlling measurements and data collection. With suitable calibration, it is then possible to do reasonably accurate measurements and present them as contours or 3D maps.

The calibrations and calculations required are extensive, but can be done on a PC.

The results can also be displayed as 3D objects which can be rotated and seen from different points of view.

3D-sårscanner

"Inspired by the Wound-project, Odense University Hospital is currently seeking resources for the development of a 3D-wound scanner. The goal is to develop a new, fast method to precisely determine the size and volume of a wound using optical, three-dimensional scanning. The precise assessment of the wound area will result in better treatment for the patient, which can help shorten the treatment period. Consequently the municipality in question will cut expenditures in the form of fewer resources needed for treatment and homecare".

Henrik Gaunsbæk; Odense University Hospital

DELTA competences

DELTA has experience in several areas related to developing instrumentation in these types of applications:

- Spotty, a web camera with mirrors, capturing 3D movement (absolute position) in real time for 13 points on a human body.
- ICAM, a True Color Camera, fitted with precise optical filters and calibrated to measure color as perceived by the human eye.
- BioView, an instrument for industrial florescent spectroscopy.
- Optical filters, thin film filters with precise defined spectral response. A recent development is a linear variable narrowband filter.
- Integrated circuits with mixed analog and digital capability, especially photo diodes and light emitting diodes.
- IR night vision camera for cars.

Imagine for instance combining a linear variable narrowband filter with a small B&Wcamera sensor, by moving the filter in front of the camera the spectral response can be recorded as a movie, knowing the position of the filter as a function of time, the spectral images recorded could well reveal detailed information, which is only seen by experts.

If the camera and light source is calibrated together, we could provide true color measurements. If more of such cameras were combined, we could provide 3D measurement capability. The product could still be rather small, handheld and relatively inexpensive, once developed.

DELTA has the capability to develop the "3D-sårscanner" mentioned above.

Fluorescence spectroscopy

Fluorescence spectroscopy has been used to evaluate dermal wounds in rats.

Fluorescence spectra of dermal lesions on 48 rats have been investigated using excitation wavelengths of 275 nm, 300 nm and 340 nm. Emission at 340 nm and 460 nm were measured in both forequarter and hindquarter lesions. Unlike 460 nm emission, intensity at 340 nm increased with time and then saturated. Control studies on intact skin and lesions in dead rats failed to demonstrate any time dependent changes. It appears that the 340 nm intensity changes is due to changes in the tryptophan level, and may reflect a factor in the wound healing process [14].

Overview on the State of Art Biomedical Optical Spectroscopy and Imaging for Future Healthcare; Key native tissue fluorophores (no dyes) [14]:

- Collagen
- Elastin
- Tryptophan
- NADH
- Flavins
- Porphyrins.

Key Wavelengths in Emission Spectra.
Key Wavelengths in Absorption Spectra.

MAGNETIC SENSORS FOR WOUNDS

INTRODUCTION

A magnetometer is a measuring instrument used to measure the strength or direction of magnetic fields.

A Hall effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall effect sensors are used for proximity switching, positioning, speed detection, and current sensing applications.

Some Flow meters operate by measuring a voltage across a moving conductor in a magnetic field (Faraday 1832).

I have found no obvious uses for magnetometers in connection with wounds, maybe except for the MR scanner.

MR scanner

Magnetic resonance imaging (MRI), nuclear magnetic resonance imaging (NMRI), or magnetic resonance tomography (MRT) is a medical imaging technique used in radiology to visualize internal structures of the body in detail. MRI makes use of the property of nuclear magnetic resonance (NMR) to image nuclei of atoms inside the body.

An MRI scanner is a device in which the patient lies within a large, powerful magnet where the magnetic field is used to align the magnetization of some atomic nuclei in the body, and radio frequency fields to systematically alter the alignment of this magnetization [16]. This causes the nuclei to produce a rotating magnetic field detectable by the scanner—and this information is recorded to construct an image of the scanned area of the body [17]. Magnetic field gradients cause nuclei at different locations to rotate at different speeds. By using gradients in different directions 2D images or 3D volumes can be obtained in any arbitrary orientation [15].

MRI provides good contrast between the different soft tissues of the body, which makes it especially useful in imaging the brain, muscles, the heart, and cancers compared with other medical imaging techniques such as computed tomography (CT) or X-rays. Unlike CT scans or traditional X-rays,MRI does not use ionizing radiation [18].

3D magnetometer

The 3D magnetometer provides tri-axis orientation, based on the magnetic field of the earth. Together with a tri-axis gyroscope, a tri-axis accelerometer it forms a complete inertial system, this is available as an electronic building block, for instance from Analog devices.

This can be used together with a digital camera to obtain 3D information using multiple images. The time of the images and the simultaneous state of the inertial sensor must be recorded.

POSITION AND ORIENTATION SENSORS FOR WOUNDS

INTRODUCTION

Positioning systems use positioning technology to determine the position and orientation of an object or person in a room, building or in the world. I can't envision direct use of such systems for wounds, except if the position accuracy is high enough so that it could be used to identify the patient.

Indirect use is already hinted above, where measurement system position and orientation can be used to implement 3D measurement systems.

The most widespread global positioning system is GPS, which also includes precise time references. In general a measurement is documented in a good (unique) way if time and position is known precisely – even if time and position has no direct bearing on the measurement.

Principles; positioning sensors

- Time of flight systems determine the distance by measuring the time of propagation of pulsed signals between a transmitter and receiver. When distances of at least three locations are known, a fourth position can be determined using trilateration.
- Optical trackers, such as laser ranging trackers suffer from line of sight problems and their performance is adversely affected by ambient light and infrared radiation. On the other hand they do not suffer from distortion effects in the presence of metals and can have high update rates because of the speed of light [19].
- Ultrasonic trackers have a more limited range because of the loss of energy with the distance traveled. Also they are sensitive to ultrasonic ambient noise and have a low update rate. But he main advantage is that they do not need line of sight [20].
- Systems using radio waves such as the Global navigation satellite system do not suffer as ambient light, but still need line of sight to maintain good accuracy.
- Spatial scan system use (optical) beacons and sensors. Two categories can be distinguished [20]:
-
- Inside out systems where the beacon is placed at a fixed position in the environment and the sensor is on the object.
- Outside in systems where the beacons are on the target and the sensors are at a fixed position in the environment.
- By aiming the sensor at the beacon the angle between them can be measured. With triangulation the position of the object can be determined.

- Inertial sensing has the advantage of not requiring an external reference. Instead it measures rotation with a gyroscope or position with an accelerometer with respect to a known starting position and orientation [20].
- Because these systems measure relative positions instead of absolute positions it can suffer from accumulated errors end therefore is subject to drift. A periodic re-calibration of the system will provide more accuracy [20].
- Phase difference systems measure the shift in phase of an incoming signal from an emitter on a moving target compared to the phase of an incoming signal from a reference emitter. With this the relative motion of the emitter with respect to the receiver can be calculated. Like inertial sensing systems, phase-difference systems can suffer from accumulated errors end therefore is subject to drift, but because the phase can be measured continuously they are able to generate high data rates [20].
- Direct field sensing systems use a known field to derive orientation or position: A simple compass uses the earth magnetic field

to know its orientation in two directions. An inclinometer uses the earth gravitational field to know its orientation in the remaining third direction. The field used for positioning do not need to origin from nature. A magnetic field is generated in a coil when an electric current circulates this coil. To measure position and orientation of a receiver in space, the emitter must be composed of three coils placed perpendicular to each other, thus defining a spatial referential from which a magnetic field can exit in any direction. The direction is given by the resultant of three elementary orthogonal directions. On the receiver, three sensors measure the components of the field's flux received as a consequence of magnetic coupling. Based on these measures, the system determines the position and orientation of the receiver with respect to the emitter attached to the reference [20].

- Hybrid systems. Most systems use more than one technology. A system based on relative position changes like the inertial system needs periodic calibration with a system with absolute position measurement. Systems combing two or more technologies are called hybrid positioning systems [20].

Principles; orientation sensors

It requires analysis of the six degrees of freedom to describe the motion of a solid object: translation in three dimensional axes; and its orientation about the objects center of mass in these axes, known as pitch, roll and yaw, with respect to a defined frame of reference.

Gyroscopes have evolved from mechanical-inertial spinning devices consisting of rotors, axles, and gimbals to various incarnations of electronic and optical devices. Each exploits some physical property of the system allowing it to detect rotational velocity about some axis [21].

There are three basic types of gyroscopes [21]:

- Rotary Gyroscope exploits the law of conservation of angular momentum which, simply stated, says that the total angular momentum of a system is constant in both magnitude and direction if the resultant external torque acting upon the system is zero.
- These gyroscopes typically consist of a spinning disk or mass on an axle, which is mounted on a series of gimbals. Each gimbal offers the spinning disk an additional degree of rotational freedom. The gimbals allow the rotor to spin without applying any net external torque on the gyroscope. Thus as long as the gyroscope is spinning, it will maintain a constant orientation. When external torques or rotations about a given axis are present in these devices, orientation can be maintained and measurement of angular velocity can be measured due to the phenomenon of precession.
- Precession occurs when an object spinning about some axis (the spin axis) has an external torque applied in a direction perpendicular to the spin axis (the input axis). In a rotational system when net external torques is present, the angular momentum vector (which is along the spin axis) will move in the direction of the applied torque vector. As a result of the torque, the spin axis rotates about an axis that is perpendicular to both the input axis and spin axis (called the output axis).
- This rotation about the output axis is then sensed and fed back to the input axis where a motor or similar device applies torque in the opposite direction, cancelling the precession of the gyroscope and maintaining its orientation. This cancellation can also be accomplished with two gyroscopes oriented at right angles to one another.
- Vibrating Structure Gyroscope are MEMS (Micro-machined Electro-Mechanical Systems) devices that are easily available commercially, affordable, and very small in size. Fundamental to an understanding of the operation of a vibrating structure gyroscope is an understanding of the Coriolis force.
- In a rotating system, every point rotates with the same rotational velocity. As one approaches the axis of rotation of the system, the rotational velocity remains the same, but the speed in the direction perpendicular to the axis of rotation decreases.
- Thus, in order to travel in a straight

line towards or away from the axis of rotation while on a rotating system, lateral speed must be either increased or decreased in order to maintain the same relative angular position (longitude) on the body. The act of slowing down or speeding up is acceleration, and the Coriolis force is this acceleration times the mass of the object whose longitude is to be maintained. The Coriolis force is proportional to both the angular velocity of the rotating object and the velocity of the object moving towards or away from the axis of rotation.

- Optical gyroscopes operate on the principle of the Sagnac effect. This effect can be seen in a ring interferometry setup. Here, a laser beam is first split by a half silvered mirror. Then the two beams traverse identical paths but opposite directions around a loop consisting of either flat mirrors or air-filled straight tubes or along fiber-optic cable.
- These two beams then recombine at a detector. When the system is rotating, one of the beams must travel a greater distance than the opposite traveling beam to make it to the detector. This difference in path length (or Doppler shift) is detected as a phase shift by interferometry.
- This phase shift is proportional to the angular velocity of the system. Often optical gyroscope units consist of 3 mutually orthogonal gyroscopes for rotation sensing about all three orthogonal rotation axes.

FUNDAMENTAL ELECTRICAL MEASUREMENTS FOR WOUNDS

INTRODUCTION

The most fundamental electrical measurements are voltage and current. Together with specialized electrodes a sensor system is formed. The measurements can be static or dynamic. For example pH or EEG.

When different electrodes are connected to an electrolyte a battery is formed.

Principles of electrodes

An electrode is an electrical conductor used to make contact with a nonmetallic part of a circuit (e.g. a semiconductor, an electrolyte or a vacuum or skin) [22].

Electrodes are used to provide current through nonmetal objects to alter them in numerous ways and to measure conductivity for numerous purposes [22]. Examples [22] include:

- Electrodes for medical purposes, such as EEG, ECG, ECT, defibrillator
- Electrodes for electrophysiology techniques in biomedical research
- Electrodes for execution by the electric chair
- Electrodes for electroplating
- Electrodes for arc welding
- Electrodes for cathodic protection
- Electrodes for grounding
- Electrodes for chemical analysis using electrochemical methods
- Inert electrodes for electrolysis (made of platinum)
- Membrane electrode assembly

Chemically modified electrodes are electrodes that have their surfaces chemically modified to change the electrode's physical, chemical, electrochemical, optical, electrical, and transport properties [23].

Principles of a battery

A Galvanic cell, or Voltaic cell, named after Luigi Galvani, or Alessandro Volta respectively, is an electrochemical cell that derives electrical energy from spontaneous redox reaction taking place within the cell. It generally consists of two different metals connected by a salt bridge, or individual half-cells separated by a porous membrane.

Volta was the inventor of the voltaic pile, the first electrical battery. In common usage, the word "battery" has come to include a single Galvanic cell, but a battery properly consists of multiple cells.

he electrical driving force across the terminals of a cell is known as the terminal voltage (difference) and is measured in volts. The terminal voltage of a cell that is neither charging nor discharging is called the open-circuit voltage and equals the emf of the cell.

Because of internal resistance, the terminal voltage of a cell that is discharging is smaller in magnitude than the open-circuit voltage and the terminal voltage of a cell that is charging exceeds the open-circuit voltage. If the voltage and resistance are plotted against time, the resulting graphs typically are a curve; the shape of the curve varies according to the chemistry and internal arrangement employed. [24]

Principles of a membrane

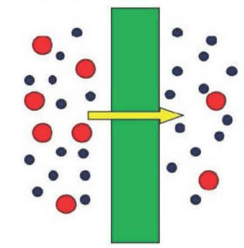
The term membrane most commonly refers to a thin, film-like structure that separates two fluids. It acts as a selective barrier, allowing some particles or chemicals to pass through, but not others. In some cases, especially in anatomy, membrane may refer to a thin film that is primarily a separating structure rather than a selective barrier [25].

A membrane is a layer of material which serves as a selective barrier between two phases and remains impermeable to specific particles, molecules, or substances when exposed to the action of a driving force. Some components are allowed passage by the membrane into a permeate stream, whereas others are retained by it and accumulate in the retentive stream [26].

Membranes can be of various thicknesses, with homogeneous or heterogeneous structure. Membrane can also be classified according to their pore diameter [25].

Membranes can be neutral or charged, and particles transport can be active or passive. The latter can be facilitated by pressure, concentration, chemical or electrical gradients of the membrane process. Membranes can be generally classified into synthetic membranes and biological membranes [25].

Schematic of size based membrane exclusion:



Principles; an electrolytic cell

An electrolytic cell decomposes chemical compounds by means of electrical energy, in a process called electrolysis. The result is that the chemical energy is increased [27].

Important examples of electrolysis are the decomposition of water into hydrogen and oxygen, and bauxite into aluminum and other chemicals [27].

Components: An electrolytic cell has three component parts: an electrolyte and two electrodes (a cathode and an anode) [27].

The electrolyte is usually a solution of water or other solvents in which ions are dissolved. Molten salts such as sodium chloride are also electrolytes. When driven by an external voltage applied to the electrodes, the electrolyte provides ions that flow to and from the electrodes, where charge-transferring, or faradaic, or redox, reactions can take place [27].

Only for an external electrical potential (i.e. voltage) of the correct polarity and large enough magnitude can an electrolytic cell decompose a normally stable or inert chemical compound in the solution. The electrical energy provided undoes the effect of spontaneous chemical reactions [27].

MEMS FOR WOUNDS

INTRODUCTION

Micro electromechanical systems (MEMS) is the technology of very small devices; it merges at the nano-scale into nano electromechanical systems (NEMS) and nanotechnology. MEMS are also referred to as micro machines (in Japan), or micro systems technology – MST (in Europe).

MEMS are separate and distinct from the hypothetical vision of molecular nanotechnology or molecular electronics. MEMS are made up of components between 1 to 100 micrometer in size (i.e. 0.001 to 0.1 mm), and MEMS devices generally range in size from 20 micrometer (20 millionths of a meter) to a millimeter (i.e. 0.02 to 1.0 mm).

They usually consist of a central unit that processes data (the microprocessor) and several components that interact with the outside such as micro sensors. At these size scales, the standard constructs of classical physics are not always useful.

Because of the large surface area to volume ratio of MEMS, surface effects such as electrostatics and wetting dominate volume effects such as inertia or thermal mass.

MEMS became practical once they could be fabricated using modified semiconductor device fabrication technologies, normally used to make electronics.

These include molding and plating, wet etching (KOH, TMAH) and dry etching (RIE and DRIE), electro discharge machining (EDM), and other technologies capable of manufacturing small devices [28].

MEMS applications

In one viewpoint MEMS application is categorized by type of use.

- Sensor
- Actuator
- Structure

In another view point MEMS applications are categorized by the field of application (commercial applications include) [28]:

Inkjet printers, which use piezoelectrics or thermal bubble ejection to deposit ink on paper.

- Accelerometers in modern cars for a large number of purposes including airbag deployment in collisions.
- Accelerometers in consumer electronics devices such as game controllers, personal media players, mobile phones, and Digital Cameras. Also used in PCs to park the hard disk head when free-fall is detected, to prevent damage and data loss.
- MEMS gyroscopes used in modern cars and other applications to detect yaw; e.g., to deploy a roll over bar or trigger dynamic stability control. MEMS microphones in portable devices, e.g., mobile phones, head sets and laptops.
- Silicon pressure sensors e.g., car tire pressure sensors, and disposable blood pressure sensors.
- Displays e.g., the DMD chip in a projector based on DLP technology, which has a surface with several hundred thousand micro-mirrors or single microscanning-mirrors also called micro-scanners.

- Optical switching technology, which is used for switching technology and alignment for data communications.
- Bio-MEMS applications in medical and health related technologies from Lab-On-Chip toMicroTotalAnalysis (biosensor, chemo-sensor).
- Interferometric modulator display (IMOD) applications in consumer electronics (primarily displays for mobile devices), used to create interferometric modulation – reflective display technology as found in mirasol displays. Fluid acceleration such as for micro-cooling

MEMS materials

The fabrication of MEMS evolved from the semiconductor process technology, i.e. the basic techniques are deposition of material layers, patterning by photolithography and etching to produce the required shapes [29]. Different materials can be used [28]:

- Silicon is the material used to create most integrated circuits used in consumer electronics in the modern world. The economies of scale, ready availability of cheap high-quality materials and ability to incorporate electronic functionality make silicon attractive for a wide variety of MEMS applications. Silicon also has significant advantages engendered through its material properties. In single crystal form, silicon is an almost perfect Hookean material, meaning that when it is flexed there is virtually no hysteresis and hence almost no energy dissipation. As well as making for highly repeatable motion, this also makes silicon very reliable as it suffers very little fatigue and can have service lifetimes in the range of billions to trillions of cycles without breaking.
- Polymers. Even though the electronics industry provides an economy of scale for the silicon industry, crystalline silicon is still a complex and relatively expensive material to produce. Polymers on the other hand can be produced in huge volumes, with a great variety of material characteristics. MEMS devices can be made from polymers by processes such as injection molding, embossing or stereo-lithography and are especially well suited to microfluidic applications such as disposable blood testing cartridges.
- Metals can also be used to create MEMS elements. While metals do not have some of the advantages displayed by silicon in terms of mechanical properties, when used within their limitations, metals can exhibit very high degrees of reliability. Metals can be deposited by electroplating, evaporation, and sputtering processes. Commonly used metals include gold, nickel, aluminum, copper, chromium, titanium, tungsten, platinum, and silver.
- Ceramics. The nitrides of silicon, aluminum and titanium as well as silicon carbide and other ceramics are increasingly applied in MEMS fabrication due to advantageous combinations of material properties. AIN crystallizes in the wurtzite structure and thus shows pyro-electric and piezoelectric properties enabling sensors, for instance, with sensitivity to normal and shear forces. TiN, on the other hand, exhibits a high electrical conductivity and large elastic modulus allowing to realize electrostatic MEMS actuation schemes with ultrathin membranes. Moreover, the high resistance of TiN against biocorrosion qualifies the material for applications in biogenic environments and in biosensors.

NOTES

INTELLIGENT MATERIALS AND TEXTILES

Intelligent textiles	List of companies with interesting intelligent textiles.	
HandyWear	Company:	Handy Wear http://www.dr.dk/P4/Vest/Nyheder/IkastBrande/2012/03/14/163008.htm
	Product:	Intelligent Støttestrømpe
	Technology:	?
	Features:	Controlled by smarthone
	Marked:	Expected on the market witin 7-8 year
	Others:	Placed in Ikast, near Herning
Danfoss Polypower	Company:	Danfoss Polypower www.polypower.com
	Product:	Dielectric electroactive polymer (DEAP) in the form of an elastomeric film coated on both sides and connected to a circuit. Applying a voltage generates an electrostatic pressure; and opposite.
	Technology:	DEAP
	Features:	Dynamic, precise, lightweight, flexible, proportional, sensitive, completely silent.
	Marked:	The material is sold by the meters, to developing companies and others.
	Others	Nordborg
Macro Fiber Composite – MFC	Material:	Macro Fiber Composite (MFC) e.g. www.smart-material.com
	Product:	The leading low profile actuator and sensor, offering high performance, durability and flexibility. Available as an elongator (P1-type) and contractor (P2-type), the applications are ranging from vibration control, structural control (morphing), strain sensing, guided wave transducer and energy harvesting. Available in over 20 different standard sizes, it is also available in customized sizes to meet specific application requirements, including array configurations.
	Technology:	
	Features:	Flexible and durable High strain capabilities, up to 2000ppm Directional actuation and sensing Available as elongator (d33 mode) and contractor (d31 mode) Conforms to surfaces, typically bonded Readily embeddable into composite materials Damage tolerant Sealed package
	Marked:	
	Others:	

NOTES

INPUT REGARDING SENSOR TECHNOLOGIES

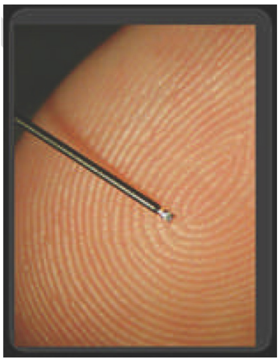
Input; sensor technologies

Miscellaneous input.

Fiber optic pressure sensor

Samba Preclin 420/360 Transducer

Ultra-miniature fiber optic pressure sensor – no bigger than a grain of salt on a hair!
Highly sophisticated, accurate, fast and sensitive instrument designed to measure pressure in gas or liquid.
Constructed with patented state-of-the-art micro mechanic and fiber optic technology.
A first-class tool for building knowledge and solving problems in numerous application areas.



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