S3 Project Elective Part 3: Biomedical Sensors and Instruments Summary

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1 Introduction

This paper is a summary of the reading we did from the book Biomedical Sensors and Instruments for a part of our project elective [1]. From this elective, we learned the characteristics of a measurement system and about examples of certain devices. From the physiological variables we might like an aerospace health monitoring device to measure, we then read about the sensors that could measure some of those general quantities: motion, force, pressure, temperature, evaporation, humidity, and bioelectric signals. The principles of those sensors are briefly studied.

This summary starts with the fundamental concepts of signals and systems. Afterwards a few parameters are discussed with respect to the basic principles of their characteristics and what the principles are of measuring them. The parameters discussed have been chosen, since they can be of use for creating an all-round health monitoring device.

The sections on pressure and bioelectric signals are most important for our Mars project. In the end our topic changed to measuring variables related to stress. Pressure and bioelectric signal measurement can be used for this.

2 Fundamental Concepts of Signals and Systems

This section discusses the basic concepts of signals and systems. The focus of the system is mainly on measurement systems. Measurement is defined as a procedure done by an observer in which a quantity of an object is determined. The quantity is a value that characterizes the object by identifying which state the object is in or what property it has. For biomedical measurements, the quantities are usually dependent on time.

A signal is part of what is obtained in a measurement procedure. It is the component that actually contains the information for the object. To find the wanted quantity, which depends solely on the observer, the signal is analyzed. Through analysis, noise (or unwanted component) may be filtered out.

Overall, a measurement system is a 'box' that receives an input and delivers an output, which is a wanted quantity. In the 'box', a sensor translates physical quantities into electrical signals, which is analyzed, and presented as visualized data, given as output (see figure below).

Figure 1: The overall big picture of how measurement systems work

3 Motion and Force Measurement

In motion measurements, coordinates are used as units to describe the movement. There are many methods in which motion can be measured. One of the more basic tools that are used to capture movement is the video camera, but we will not focus on this method, due to it's fixed coordinate system.

A simple and accurate tool for motion measurement is a goniometer. This sensor can be attached to the human joint, all the while without disturbing the user's movements. The principle of this measurement device is that it measures the changes in angle. This is put into a coordinate system that is constantly moving.

The main principles behind motion sensors is the measurement of displacement, velocity, acceleration, and if applicable, rotation. There are also multiple ways in which these measurements can be made. One is via contact sensors, such as potentiometers, photoencoders, and magnetic sensors. Although, if forces are small, the friction from the potentiometers may result in an unreliable measurement.

For example, an accelerometer works by using the principle of F=ma or Force = mass x acceleration. An accelerometer is made up of a mass attached on a spring, all of this hidden inside a little box, which we end up calling a sensor. As the box moves, the mass exerts a force on the spring. The acceleration is measured from the calculations of the force. (See figure below.)

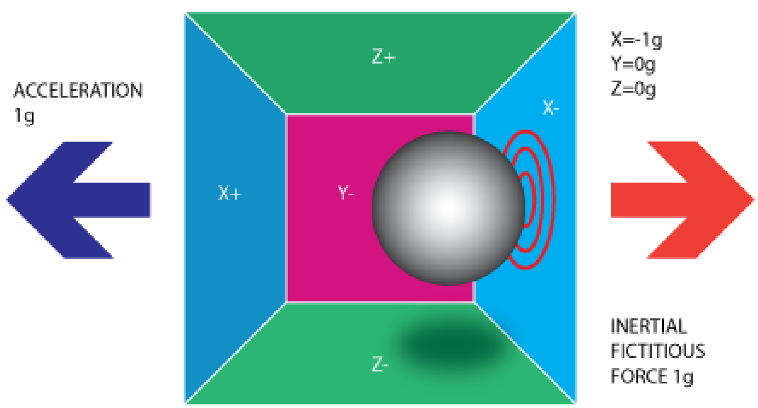


Figure 2: Image depicting the inside of an accelerometer, which in turn, describes how it works.

As for force measurement, when done on a body in motion, inertial forces have to be taken into account. Force can be measured from acceleration measurements, therefore it can be measured with multiple accelerometers.

For ground force measurements, or the amount of force that a person is exerting on the ground, especially when walking (which can be useful for gait analysis), force plates can be used. Currently force shoes, which are shoes enforced with force plates, are used in space.

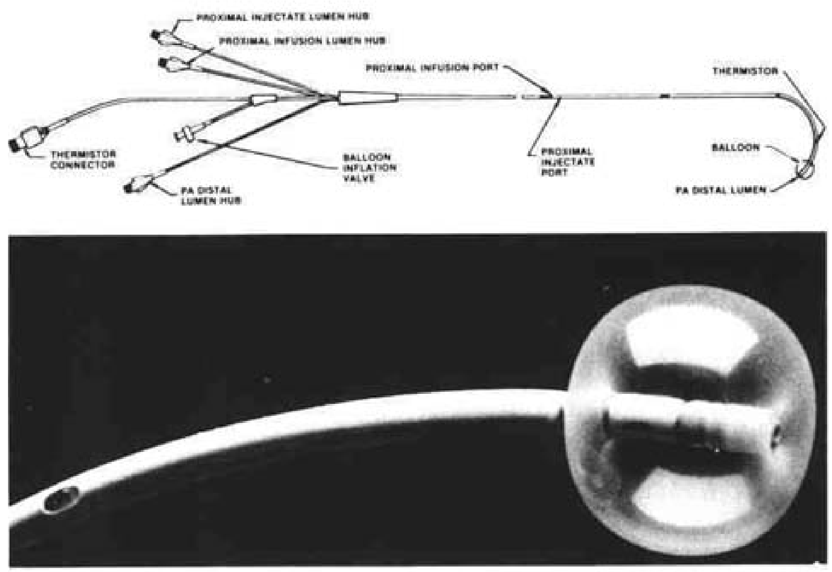
Because the human body is not rigid surfaces, it is important that the reference points for the coordinate systems are standardized when combining data from multiple sensors.

4 Pressure measurements

Pressure is defined as the force exerted per unit area. Physiological pressures are normally measured and expressed relative to the atmospheric pressure. Pressure is measured in relation to the atmosphere and therefore it is normally unnecessary to specify the absolute atmospheric pressure. However, when the pressure in the body is measured by an indwelling sensor that measures absolute pressure, the physiological pressure has to be determined by substituting atmospheric pressure from the obtained absolute pressure.

Pressure in the cardiovascular system can be measured in different ways. Arterial blood pressure is routinely measured is in most patients, and is accepted as index of circulatory condition. The quantities measured are systolic and diastolic pressure. In the systolic phase, the aortic valve of the heart is open, and the arterial pressure reflect the mechanical activity of the heart ventricle. In diastolic phase, the aorta is closed, and then the time course of the arterial pressure reflects the movement of the blood from the aorta to the peripheral vascular system. The arterial pulse pressure, which is defined as the difference between systolic and diastolic pressures, is an important quantity relating to the characteristics of the heart and the arterial system.

Pulmonary wedge pressure is also commonly measured. It is the pressure observed when the catheter introduced into the pulmonary artery is wedged at a branch of the pulmonary artery. The pulmonary wedge is in between the true capillary pressure and the pressure in the left atrium, and it is used as an estimation of left atrial pressure. The image below is that of the Swan Ganz catheter, which is the measurement device often used for this parameter.



Courtesy of Edwards Labs.

Figure 4.6. Swan-Ganz PÅ catheter.
A. Left. Lumens and ports.
B. Right. Balloon inflated.

Figure 3: Image of Swan Ganz catheter, which is used to measure the pulmonary wedge pressure.

Central venous pressure is the pressure in the central vein close to the right atrium, and is the resulting pressure developed by venous elasticity and intrapleural pressure. The absolute pressure in the intrapleural space is normally between below 1 kPa. Intrapleural pressure is normally almost equal to atmospheric pressure, and the central venous pressure can be an index of the blood volume in the venous system and elasticity of the veins.

Atmospheric pressure is applied uniformly to the human body. Thus the sensor which measures pressure relative to the atmosphere is not affected by a change in the atmospheric pressure. However, when a sensor which measures absolute pressure is used, variations in atmospheric pressure should be considered.

Due to gravitational force, the pressure at a specific site may change when there is a change in posture. To avoid any ambiguity, in this regard, it is postulated that most clinical pressure measurements are performed with the patient in a well-defined posture. However, even if the posture is the same, some ambiguity still remains due to the level at which the sensor is placed. The reference point at which the pressure is zero is used in determining the appropriate level to place the sensor. There is a site in the cardiovascular system where the pressure remains constant regardless of posture. It has been shown that right atrial pressure is the most stable pressure in relation to posture changes. This is important for measurements while someone is moving.

5 Temperature sensors

Temperature is measured at many different sites of the body for clinical diagnosis and patient monitoring. In humans the temperature of the central part of the body is stabilized by a physiological thermoregulatory function, and the deep tissue temperature at the central part of the body is called the called the core temperature or deep body temperature. When talking about body temperature, the core temperature is most often used as an indication even though the body is not uniform but can vary from site to site.

The range of a skin temperature measuring device can 0-50 degrees celsius due to different circumstances that the body can be in. Although, for some cases such a device needs a smaller range to be more precise. The resolution, absolute accuracy, and response time of the thermometer required for skin temperature vary according to the purpose.

Different types of temperature sensors are available of which thermistors are one (See image below). A thermistor is a semiconductor-resistive temperature sensor made by sintered of metals such as manganese, cobalt, nickel, iron or copper. The resistance of a thermistor has a negative temperature coefficient, typically about -0.04/K. It is suitable for use in physiological temperature measurements, where relatively high resolution in required in a narrow temperature range.

Figure 4: What a thermistor looks like. It is a very small sensor, therefore, it can be easily integrated into clothing

Another type of sensor is a thermocouple, which is a thermoelectric sensor. A circuit composed of two dissimilar metals A and B provides an electromotive force that depends on the temperature difference between two junctions. It is known as the Zeebeck effect.

A thermoresistive element in another sensor type, which is made from a pure metal. It has the advantages that is has a constant temperature coefficient and linear output can be obtained in a wide temperature range. These advantages are less significant for biomedical applications, where other specifications are prefered. For this type of sensor platinum is the most common material to use.

The resonant frequency of a quartz resonator has a temperature coefficient and can be used as a temperature sensor. The temperature coefficient of a typical crystal temperature sensor ranges between 10 and 100 100ppm/K. The crystal temperature sensor has an almost uniform temperature coefficient is a wide temperature range.

6 Measuring Evaporation and Humidity

Something besides temperature, but which is related in some ways, is evaporation. Water loss via the skin can be measured by devices. This loss is mediated via two physical processes, diffusion through the epidermis and low level sweat secretion via the sweat glands.

Measuring humidity of air can be measured by an electrolytic water vapor analyzer. The measurement cell in electrolytic water vapor analyzer is usually a cylindrical tube through which a continuous carrier gas flow is conducted. Inside the tube two helically winded platinum wires are arranged and supplied from a direct current source. A thin layer of phosphor pentoxide is deposited between the spirals. Water vapor is absorbed by phosphorus pentoxide. A small electrical current passes between the platinum wires. The magnitude of this current is related to the water content.

Another way of measuring humidity is via an infrared water vapor analyzer. It is based on the infrared absorption properties of water vapor at 2.37 um band. The measurement cell is usually divided into two tubes, one containing the gas under study study and the other a reference sample. With a humid gas in one tube and the dry reference gas the detector records an imbalance signal and can in this way measure the humidity of the test sample.

Evaporation water loss from the skin is estimated by passing a continuous flow of gas with a known water content and a known flow rate through the measurement chamber. The water content of the gas can be measured by an electrolytic water vapor analyzer.

The human body is under undisturbed conditions surrounded by a water vapor boundary layer. If the vapor pressure and temperature distribution are known, the evaporation water loss and convective heat loss from the skin surface can be calculated.

7 Bioelectric Measurements

In hospitals heart rhythm is a very common measurement being made. Electrodes are used for this measurement since it uses electrical signals and they can also be used to measure other signals, like an EMG. Most electrical events in the human body have amplitudes below 1V. The resting potential of a cell may be as high as 0.05-0.1V, whereas voltages recorded from the skull related to the activity of the central nervous system may be as low as a few microvolts. This shows that measuring these signals should be really precise. Table 1 shows some common physiological signals and the range in output they give.

Bioelectrodes are devices that transform biochemical and physiological signals into electrical currents or generate such signals from electrical currents. Measurement devices make use of the fact that electrolytes in biological solutions and body tissue contain charged particles, ions. The electrode's function is to transfer charge between ionic solutions and metallic conductors. This charge will turn into a signal which can be

Electrophysiological Parameter	Signal Range (mV)
Electrocardiography (ECG)	0.5-4.0
Electroencephalography (EEG)	0.001-0.1
Electrocorticography	0.1-5.0
Electrogastrography	0.1-5.0
Electromyography (EMG)	-
Electrooculography (EOG)	0.005-0.2
Electroretinography (ERG)	0.01-0.6
Nerve potentials	0.01-3.0

Table 1: Electrophysiological variables and their magnitude range

interpreted.

As a result of the charge distribution close to the electrode surface, the electrode itself acquires a potential. It is not possible to measure the potential of a single electrode with respect to a solution. Therefore, electrode potentials are always measured in relation to a standard electrode. Such an electrode is the standard hydrogen electrode (SHE).

For ECG measurements, a Silver-Silver Chloride electrode can be used. This electrode type consists of a metal silver substrate coated with AgCl. When such an electrode comes into direct contact with an electrolyte containing chloride ions, an exchange takes place between the electrodes. Another type of electrode that is used for ECGs is a stainless steel one. This type of electrode polarized far more than silver-silver chloride.

The invention of the field effect transistor made it possible to design amplifiers with a very high input impedance. With such an amplifier as input stage, it is possible to design electrodes that can be used directly on the skin without paste or low-ohmic paths between the electrode and the tissue. Such electrodes are called dry or capacitive electrodes.
It works with a metal plate that is placed against the stratum corneum, which is the outer layer of the skin with dead cells, and a metal electrolyte interface is created. The impedance is mainly resistive because of the stratum corneum that works with as an isolating medium. The deeper parts of the skin have higher conductivities. Therefore, there is a capacitor with the metal plate, the dermis as conducting plates, and the stratum corneum as the dielectric. A disadvantage of dry electrodes is that the high impedance amplifier is very sensitive to electric fields around the electrode.

The use of a pasteless electrode has been suggested for long-term applications such as space missions. High-impedance electrodes have to be used in connection with these types of electrodes because of the high skin-to electrode impedance.

Next to ECG signals, EMG signals can also be measured by electrodes. Two electrodes are used to record the electromyographic (EMG) signal. Surface electrodes are used on the surface of a muscle or skin above the muscle under study. Needle or wire electrodes are inserted into the muscle for signal extraction. Electrodes for EMG can be used singularly or in pairs.

8 Discussion

For a most effective measurement system, it is obvious that it must be known beforehand what variables are needed to be measured. Then it is best to look at the sensor principles for those variables. In this part of our elective, we looked at the concepts of measuring the following variables: pressure, motion, force, bioelectric, biomagnetic, temperature, heat flow, and evaporation. For the variables that may be directly measured through blood or other body fluids, only the concepts of indirect measurements were studied.

From the readings, it can be generalized that sensors function by translating physical quantities to electrical quantities, which is then brought to a realization. As for a measurement system, the sensor should obtain data that is processed and visualized for presentation to the user.

To break it down, the first phase for a measurement system is the data sensing phase. This is when the sensor does its job. The reliability of the sensor is important. In biological measurements, data can be highly affected by movement. For a most reliable wearable measurement system, there should be least errors when the user is in motion.

The second phase is the analysis of data, in which the signal obtained by the sensor is processed. The needed data is computed and noise, or unwanted data, is filtered out. The final data is stored and presented in the third phase. How the data is visualized depends on who it is presented to. This could either be directly to the user or to their doctors.

After having learned how measurement systems work, a question has been raised: How can all the sensors be integrated into a system that obtains, analyzes, and presents the data? This system should be specialized for astronauts. An idea is to integrate electrodes and other sensors into clothes.

Another idea is to use implanted sensors. The difficulty of this method is the means of charging the battery. With the necessity of sending data wirelessly, the batteries for implanted sensors cannot last long enough for its use to be convenient. Nevertheless, this may open a new area of research, since wireless charging may be an option. The risks and dangers of wireless charging towards human health is currently unknown. Future research should study how wireless charging may affect human tissue and investigate the possibility of implanted sensors.

References

[1] T. Togawa, T. Tamura, and P. Oberg. *Biomedical Sensors and Instruments.* CRC press, 2011.