Conception and development of an Expansion Sensor for the use in Limb Plethysmography

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Abstract

This paper shows the development of a novel sensor system for the application in the field of diagnostics of blood vessels. In a development project between Fraunhofer IPA and Gutmann Medizinelektronik e.k. an older sensor principle, using quicksilver for the detection of the change of expansion, is replaced by a new sensor concept. The new sensor system uses a combination of fixed and flexible sensor - modules to detect the expansion of the outline of a limb. The core of the sensor system is a hall sensor, which is integrated in a fixed module. In this paper we show the methodic development process of the sensor and the working concept of the final prototype.

1. Introduction

The aim of „Limb Plethysmography“ is to check for narrowing or blockages of blood vessels in the arms or legs. [7]. With this test blocked vessels in the arms or legs can be ruled out. Especially the functionality of small vessels and venous valves can be tested. During the test the blood is blocked in defined positions for a short period of time. A sensor, which is placed around arm or leg measures the change in outline from which the change of volume can be calculated.

The company Gutmann Medizinelektronik e.k. has got an older sensor system, which measures the expansion with a quicksilver sensor. This sensor has got a very good accuracy and a very high resolution. Quicksilver is liquid at room temperature and has got a very good thermal and electrical conductivity. On the overhand quicksilver at a high concentration at free air is toxic and the development, production and distribution will be forbidden according to (EG) Nr. 1102/2008.

Gutmann Medizinelektronik e.k. and Fraunhofer IPA developed a new sensor which uses the Hall Effect for the detection of changes in the outline of human limbs.

The requirements for this sensor are very high. During the development-process different sensor principles were tested. The main challenge is the high resolution and high accuracy of the sensor system as a whole.

The final solution is a combination of fixed and flexible sensor-modules, which uses the Hall Effect to detect the change in outline.

1.1. Requirements

As mentioned in the section above the sensor sytem is used in the medical environment. During two Master-thesis at Fraunhofer IPA, the needed requirements were derivated from the application and setting in which the sensor is used.
The sensor system has to have the following characteristics:

- Easy use and applicability by health personnel
- The temperature in the operational area: between 10°C and 50°C.
- The sensor system needs to be insensible to normal disinfectants.
- The interface of the sensor system has to be digital (SPI, I2C or RS232)
- The sensor system should not contain any toxic substances.

The most important requirements are of course the high accuracy and the high resolution. An accuracy of 2µm is needed.

2. Development Process

The new sensor system was developed on the basis that a sensor technology, which was used for decades and carried in its practicality in everyday medical-sets had to

be replaced with a new sensor principle. The new sensor technology wasn't defined at the start of the course of development.
An Assessment of different sensor principles was carried out at the beginning of the development. The method of product development methodology [3] was used to collect, evaluate and preselect different sensor principles. We identified two physical measuring principles for the application.
For example the technology of using conductive polymer to measure the change in resistance due to the change in outline was tested. Here the accuracy wasn't as good as expected and therefore the results are not shown in this paper. The best results were achieved using Hall Sensors for the detection of the change in outline of a sensor band.

3. Overall System Design

The overall system consists of a measuring element and a chain of gliding elements and one adjustable closure. Closure and gliding elements are used here to match the size of the object to be measured. The gliding elements also permit an optimal distributed pressure between system and limb and minimize the friction of the rotating measuring tape.

Picture 1: Sensor System as a whole

The sensor element is used to determine the change of outline and thus the volume of contain. This sensor task is performed by a miniaturized electronics; the core element is a miniature Hall Sensor Array. The use of this technology allows a resolution of up to 0.5µm and also ensures a high robustness. The sensor can be used in difficult conditions and the cleaning of the sensor system is unproblematic. The sensor is mounted in a specially designed case, which has optimal density and insensitivity. At the same time the case was optimized in terms of ergonomics and friction losses.

The system concept includes a visual display, which shows function and displacement directly on the sensor.

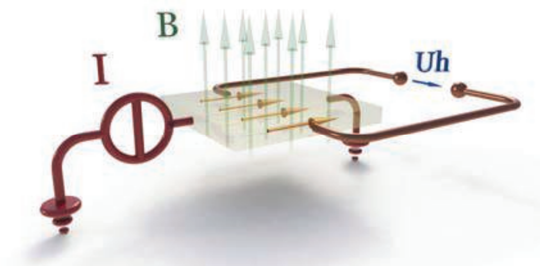
This prevents a wrong measurement as the user (health personnel) doesn't have to switch between sensor and external PC and therefore can applicate the system directly at the patient's limb. This shortens the examination time and increases the comfort for the patient.

4. Sensor System

The sensor system which is discussed here is based on the principle of incremental sensors using magnetic field sensor as basis technology. Special emphasis was made on the high accuracy and repeatability of the system. The data transfer was implemented on the basis of an integrated I2C bus. The digital interface is important for the internal data processing and for the data communication to the central unit.

4.1. Measurement Principle

When the magnetic field is measured using a Hall sensor, a current conductor is positioned in a magnetic field. In this way a voltage is generated perpendicular to both the current and the magnetic flux density and it is proportional to both parameters. Figure 2 shows graphically the basic context.



Picture 2: Graphical description of the measuring principle

On the basis of Hall Effect the course of the field can be detected when using several Hall sensors and thus the position of the sensor over a pole pair can be determined. After a reference-procedure the absolute position of extended pole pairs are calculated. The sensor has a resolution of 12 bits per pole pair. This corresponds to a theoretical resolution of 0.5 µm for polpair with a length of 2 mm.

4.2. Change of volume

In the actual case the change in the length of the strip length gives the change of the volume enclosed by the sensor body. This in turn allows a conclusion to the volume enclosed by the sensor volume, which is proportional to the pressure within the sealed object from the sensor. The Change of volume can be derivate from the following formula:

$$\frac{\Delta V}{V} = \left(\frac{\Delta V}{U}\right)^2 \cdot 2 \cdot \frac{\Delta U}{U} = \left(\frac{\Delta l}{l}\right)^2 \cdot 2 \frac{\Delta l}{l}$$

4.3. Conclusion

A novel sensor for Limb Plethysmography was developed. The new sensor system uses a Hall Sensor to measure the change of outline. The sensor can be used in the medical environment and has got a very high resolution and accuracy. The new geometry of the sensor housing and the gliding elements minimizes the effect of pressure of the tissue.

5. References

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