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An Autonomous Sensor for Force Measurements in Human Knee Implants

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Abstract

In vivo monitoring of human knee implants after total arthroplasty increases the knowledge about articular motion and loading conditions. The proposed autonomous sensor executes autonomously force measurements into a protected environment and wirelessly transmits data directly from the inside of the implant to an external readout unit. The forces transmitted across the knee joint during normal human activities such as walking, running or climbing can be directly measured. Batteries are completely eliminated by harvesting energy from an externally applied magnetic field collected by a miniature coil within the implant. The remote powering and receiving coil can be located on the patient's leg. The data generated from this device will provide inputs for new designs, techniques and implementation. Furthermore, the device can be used to improve design, refine surgical instrumentation, guide post-operative physical therapy and detect the human activities that would overload the implant.

Keywords: low-power sensor, autonomous sensor, telemetry systems, implantable monitoring systems, inductive powering for sensor systems.

1. Introduction

Autonomous sensors are devices that autonomously execute measurement functions in the measurement environment. They are unwired from the acquisition unit, have both independent power source and ability to measure and transmit data. Their use widens to applications where wires connecting a data acquisition unit and the sensor element cannot be used [1, 2]. In orthopedic science, autonomous sensors are used for accurate measurements inside the human body to avoid risk of infections or skin damage: the connections of the sensor with cables limit the patient's mobility and causes skin irritations or infections. The proposed autonomous sensor executes autonomously force measurements into a human knee implant and wirelessly transmits the data directly from the inside of the implant to a readout unit. Literature reports many examples of autonomous sensors equipped with batteries, but other power sources techniques are emerging such as those exploiting harvesting modules and inductive links. In the proposed autonomous sensor, the batteries are eliminated by using a miniature coil within the implant, which harvests energy from an externally applied magnetic field. A better knowledge of the joint forces is required to improve implant design and to help the patients not to overload the implant. Furthermore, an important use of in-

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vivo joint forces is the preclinical testing of new implants or fixation technologies: mechanical tests on new implants can be improved defining forces and moments of realistic values and directions.

2. Autonomous Sensor

The proposed autonomous sensor is composed by a customized force transducer, low-power electronics for RF communication and energy harvesting capabilities. The concept and the technology developed in the project can find application in solutions without batteries and cables. The deformation of the articulating surface, the stress distribution in the implant and the mechanical behavior of the polyethylene insert are related to the joint load [3]. A customized transducer was developed to measure the dynamic and static forces and the center of pressure of the polyethylene insert. The electronics, including the sensing elements and the antenna, is fully contained within the polyethylene insert, which can be hermetically sealed using laser welding techniques (Fig. 1). Therefore, the proposed instrumented implant is identical to the original one.

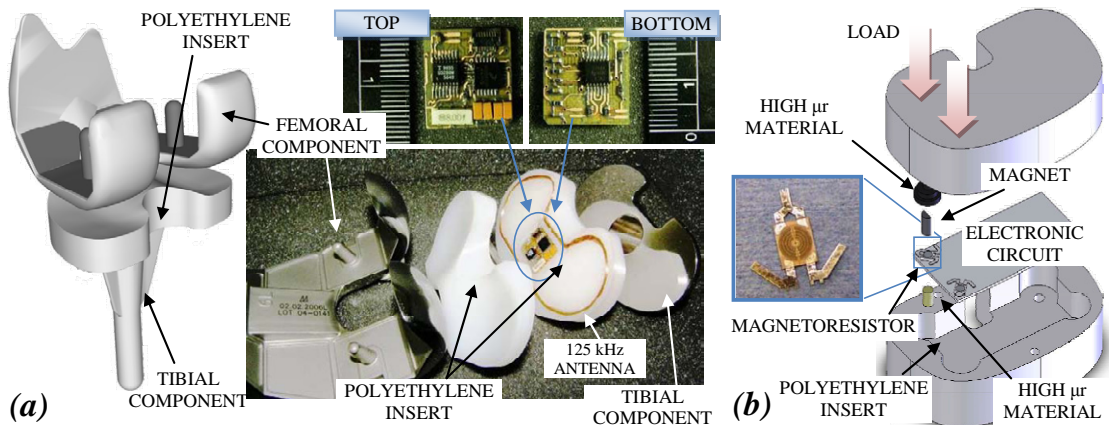


Fig. 1: Schematic configuration of a typical human knee implant and images of the autonomous sensor (a). Basic structure of the realized device for the characterization of the magnetoresistive sensors (b).

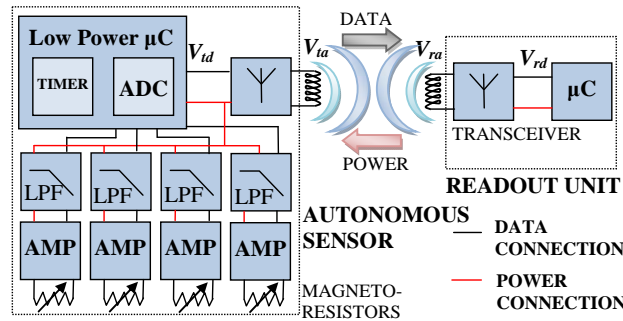


Fig. 2: Block diagram of autonomous sensor system and readout unit.

In Fig. 2 a block diagram of the autonomous sensor is reported. The autonomous sensor consists of magnetoresistive sensors for strain measurements, a low-power microcontroller (S08QB) with an AD converter (12 bit) and a transceiver (U3280M). The autonomous sensor provides signal transmission via electromagnetic coupling at 125 kHz through the coil antenna of the transponder interface and be supplied by the same electromagnetic field. The magnetoresistors used are made by AshaiKasei corp. A Sn-doped single crystal film is used as material for the sensing element. This semiconductor element is made in thin-film technology on alumina substrate. A permanent magnet is located at the front face of the semiconductor magnetoresistive element. The change in the magnetic flux density correlated to the strain is taken out as a resistance change.

3. Experimental System

The basic experimental setup is shown in Fig. 3. A polyethylene structure was fabricated for magnetoresistors characterization. In this setup configuration a laser displacement sensor was used to measure the displacement of the top surface due to the forces, while a multimeter was used to measure the resistances of the four magnetoresistors. Furthermore, custom total knee prosthesis was provided as experimental setup for wireless transmission characterization. (Fig. 3). The readout unit is connected to an external inductor and positioned as reported in Fig. 3. A multimeter monitors the powering levels of the internal circuit, while an oscilloscope monitors the transmission signals.

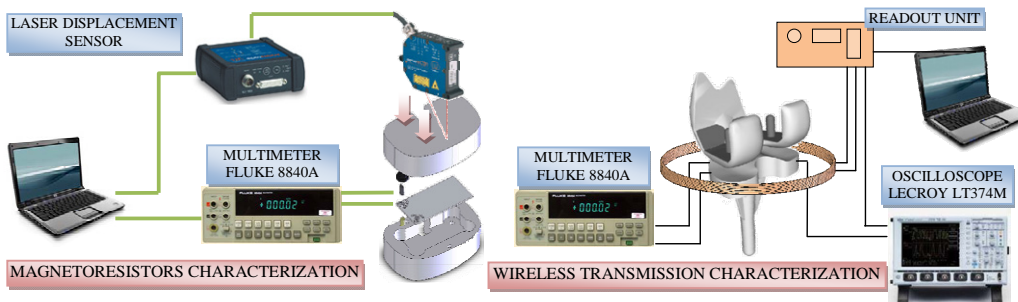


Fig. 3: Block diagram of the experimental set-up for the characterization.

4. Experimental Results

Various experimental tests are undertaken. Power consumption measurements are reported in Table 1 during the different activities: measurement, transmission and stop mode. In Fig. 4 the wireless transmission signals are monitored during communication and stop mode. The autonomous sensor has a 500 kHz of microcontroller clock during the measurement and transmission, while the clock is 16.4 kHz during stop mode. To transmit data the 125 kHz RFID transponder (U3280M) modulates the magnetic field using a damping stage; in particular the OOK modulation and the Manchester code are chosen. The clock extractor pin is used to provide a field clock for the synchronization data transfer. Moreover the device is able to generate a power supply, which is handled via electromagnetic field and the coil antenna of the transponder interface.

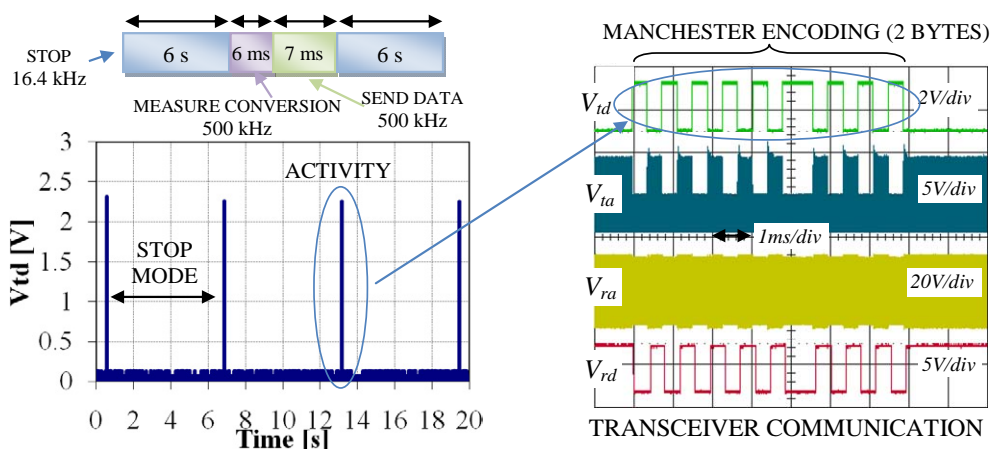


Fig. 4: Wireless transmission signals of the converted data and typical autonomous sensor activities.

Table 1: Power consumption measurements.

Activity	Voltage [V]	Current [μ A]
Readout unit - transceiver communication	12	19300
Autonomous sensor - measurement and transmission	1.8-2.5	840-980
Autonomous sensor - stop mode	1.8-2.5	150-190

Preliminary results reported in Fig. 5 show the resistance variation as a function of the distance between the magnets and the magnetoresistors: the proposed autonomous sensor works correctly where the rate of resistance change is linear and setting the operation point to a magnetic flux density from 3000 G until to 6000 G. Using the fabricated structure, the system has been characterized applying orthogonally different loads in a range up to 12 kg. In Fig. 6 the resistance measured values for different applied loads are reported. Two tests were executed in different days to analyze the repeatability. The data shows that it is possible to develop a highly accurate transducer for measurement of applied forces in knee implants. Further analyses are undertaken regarding temperature, mechanical and electronic considerations.

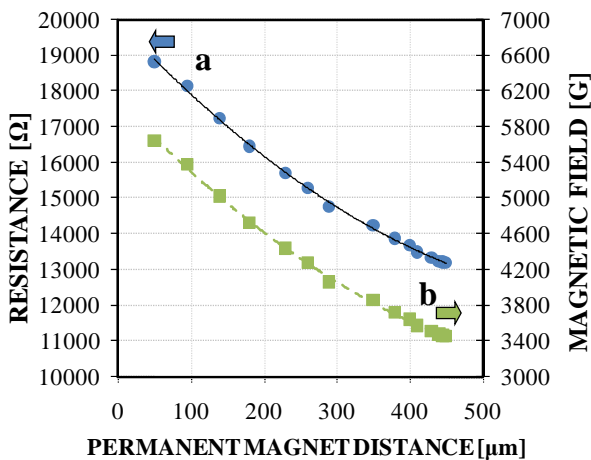


Fig. 5: Preliminary results for the characterization of the resistance (a) and magnetic field (b) vs. distance.

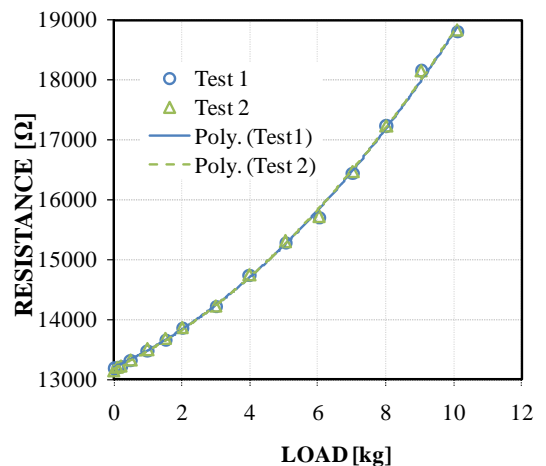


Fig. 6: Preliminary results for the characterization of the resistance vs. applied loads.

5. Conclusions

In this paper the proposed autonomous sensor for force measurements into human knee implants was presented. The experimental results showed that the proposed sensor represents a promising new system for in-vivo load monitoring of medical implants. The proposed autonomous sensor will possibly lead to new redesign regarding the function of knee implants and the treatment of patients with total knee implants.

References

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