

MEMS comb drive sensor for osteoarthritis diagnosis

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ABSTRACT

Osteoarthritis (OA) is the most common musculoskeletal disorder worldwide. Knee and hip joints are most commonly affected by OA, and their impact on public health is remarkable. The effects of OA on an individual are also considerable. The symptoms of OA, such as pain and stiffness of the joints and muscle weakness, are serious risk factors for mobility limitation and impaired quality of life. Osteoarthritis begins in the cartilage and eventually leads to the two opposing bones eroding into each other. Laboratory tests (using X-rays) for rheumatologic problems lack the sensitivity and specificity to allow their use as screening tools. Diagnosis is the critical challenge in MEMS research. This paper deals with the design of capacitive comb drive sensor for diagnosing joint-cartilage disorder including the degradation of joints and inflammation. The comparison between various stages of osteoarthritis leads to the diagnosis

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Introduction

Mechanical abnormalities of the joint are the main cause for osteoarthritis. A variety of causes- hereditary, developmental and metabolic may initiate processes leading to loss of cartilage. When bone surface becomes less well protected by cartilage, bone may be exposed and damaged as shown in figure 1. It results in inflammation around the bone. To control this risk, joint replacement surgery is done and eroding of cartilage (protective layer) can be prevented. While x-rays are used to reveal the appearance of osteoarthritic joints to diagnosticians, there is not always a direct correlation between what the x-rays show and the symptoms of osteoarthritis that a patient is experiencing (Brandt KD). We propose to use MEMS comb drive sensor to monitor displacement of joints as capacitance changes.



Figure 1: Joint affected by osteoarthritis

The sensor is placed between the affected joints in cartilage layer. Hence it provides the capacitance variations for displacement of joints when cartilage breaks off.

Bio MEMS and sensors

Attention to MEMS continues to increase Worldwide and MEMS has a phenomenal growth in the past sixteen years. Today, the extreme miniaturization of new devices has enabled examination, sensing, and monitoring from inside the patient. The electromechanical chip technology that has brought with it great value to the medical field is called Bio MEMS. Bio MEMS has improved existing medical technologies and contributed great impacts to the field. One of the most diversified fields that

show well-suited opportunities for MEMS sensors is wireless medical monitoring systems. This paper deals with the capacitive sensor. Capacitive sensing (Larry K. Baxter) is a technology based on capacitive coupling that is used in many different types of sensors, including those for detecting and measuring: proximity, position or displacement, humidity, fluid level, and acceleration.

Comb drive sensor

Capacitive comb drives are commonly used both as actuators and position sensors. It consists of a series of interdigitated tines or fingers (see figure 2). In a pair of interdigitated combs, the fingers of one comb do not touch those of the other comb, but they do slide in and out relative to each other with a variable overlap (Elwenspoek M). The fingers in MEMS combs are typically a few microns wide and 40 to 100 microns long. The gap between the interdigitated tines is normally 0.5 to 2 microns. The applied electrostatic forces typically pull on a MEMS flexure to provide highly accurate position control.

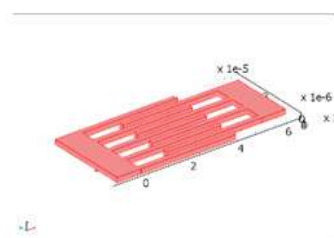


Figure 2: comb drive

Sensor structure

Capacitive sensor is attractive for this design because of its low current sensing (Robert Puers). Compute the capacitances using the electrostatics application mode's port boundary condition. The figure shows the electric potential of the comb drive's surface, silicon substrate, and bounding box. This structure has been used for the diagnosis of Osteoarthritis after joint replacement surgery (Schumacher JR).

SETTINGS	Boundary condition
BOUNDARIES 1-5,7,12,13,52,53	Zero charge/Symmetry
BOUNDARIES 8-11,14-27,42-46	Ground
BOUNDARIES 28-41,47-51	Port

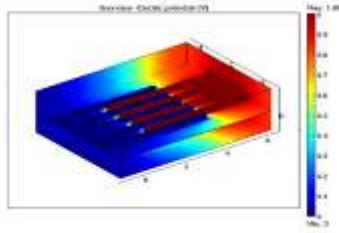


Figure 3: electric potential on the surface of the comb drive.

Sensor operation

The Sensor mechanism functions by measuring the change in displacement when it is attached to cartilage. The sensor should be able to sense even small values of displacement developed by joint.

The energy required to charge a capacitor should be equal that of the electrostatic field, which is

$$W_e = \frac{Q^2}{2C}$$

W_e is readily available in the electrostatics application mode; the software calculates itself by integrating across the domain

$$W_e = \int_{\Omega} (\mathbf{D} \cdot \mathbf{E}) d\Omega$$

Where D is the electric displacement, and E is the electric field. The capacitance C is related to charge on the two conductive plates, Q, and the voltage difference across those plates, ΔV , by

$$C = \frac{Q^2}{2W_e} = \frac{C^2 \Delta V^2}{2W_e} \Rightarrow C = \frac{2W_e}{\Delta V^2}$$

Results

Eased on radiological assessment more than 80% of people over the age of 55 have some degree of Osteoarthritis. The simulated and calculated capacitance shows the results for the various displacements of joints. In normal condition, capacitance value is 0.02pF.

The results will vary according to the various displacements by different stage of osteoarthritis. Figure 4 shows the mild osteoarthritis in which, as the displacement of joints varies capacitance will be 0.034pF.

Figure 5 shows the moderate osteoarthritis, in which the U shaped curve shows the capacitance upto 0.045 as a result of swelling. Figure 6 shows the severe osteoarthritis, in which cartilage gets completely eroded and the obtained capacitance will be 0.9pF.

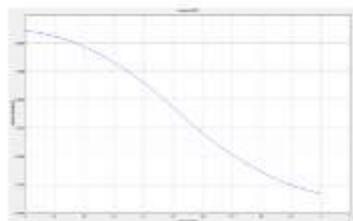


Figure 4: Mild Osteoarthritis

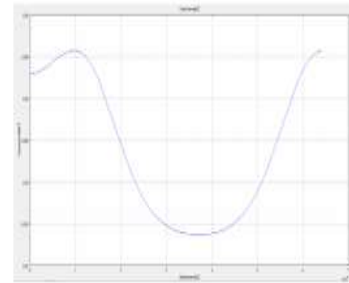


Figure 5: Moderate osteoarthritis

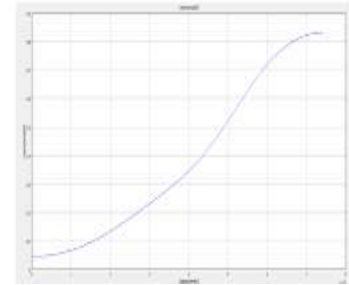


Figure 6: Severe Osteoarthritis

Conclusion

There is no cure for osteoarthritis, but with early recognition and treatment, it is possible to minimize and delay joint damage and complications of the disease, such as chronic pain and disability. Thus the different displacement of joints for Osteoarthritis has been analysed. The above results gives us the fact that comb drive sensor aids in determining prognosis or planning treatment.

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