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Low Power Wearable sensing system for the Monitoring of Knee Joint Instabilities

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Summary:
The anterior cruciate ligament tear causes instability to the knee joint, and it is very common among young adults. The diagnosis in many cases are subjective because it is exclusively based on the physical examination methods of the attending physician. Also, certified instruments exist. However, they are bulky and uncomfortable for the patient. For this reason, a flexible, capacitive sensor has been developed along with the wireless front-end electronic system. Both the stretchable sensor and the flexible board adhere to the leg like a patch, being comfortable to wear and light to carry. The whole sensor unit has been tested with a knee simulator, proving that it is suitable for everyday clinical use.

Keywords: ACL rupture diagnosis, strain gauge, microcontroller, Bluetooth, wearable sensors.

Introduction

Currently, the diagnosis for anterior cruciate ligament (ACL) injury is done using a bulky and uncomfortable system that is difficult to operate [1, 3] and it is operator dependent. A full analysis of the pathological changes due to an ACL rupture requires an accurate measurement system that is reproducible and repeatable [5] and is till today, a challenge. Additionally, the sensing system should be wearable, lightweight, comfortable for the patients to wear and for the doctors to use. To achieve this goal, in this paper we describe (1) a newly developed flexible capacitive strain gauge sensor [4] and 2) An electronic front-end integrating the sensor optimized for this application. The battery powered system acquires data, process it and, send the data wirelessly via Bluetooth to a receiver. The overall system is tested on a knee simulator to analyze its functionality and reliability.

Electronic System Overview

To make the system suitable for clinical use, the device must be (1) light weight and wearable, (2) must allow wireless data transfer, and (3) permit a long battery life. The system overview is shown in Fig. 1:

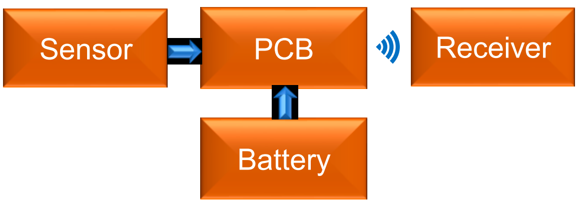

Fig. 1. System Overview.

Capacitive Sensor: Design & Fabrication:

The sensor is a stretchable capacitive strain gauge. It consists of a polydimethylsiloxane (PDMS) layer substrate and a carbon black layer obtained by doping PDMS (Neukasil® RTV-23 and RTV-17) with carbon particles (ENSACO® 250 P from TIMCAL Ltd., Bodio, Switzerland). The carbon black layer is laser patterned to obtain an interdigital structure consisting of 279 fingers [4] as shown in Fig. 2:

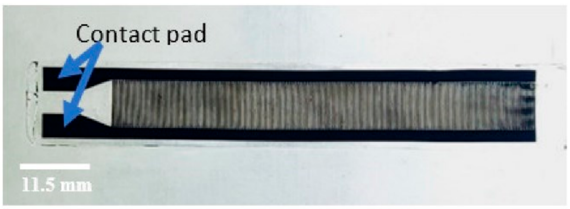

Fig. 2. Capacitive strain gauge sensor. [4]

The sensors obtained are reproducible [4]. The capacitive strain gauge sensor is connected to the electronic board using screws.

PCB: The microcontroller CC2652R1 (Texas Instruments) is chosen for the electronic data acquisition and processing, the properties of which satisfy the system requirements. The microcontroller is powered by a battery. A battery protection circuit is used to prevent over charging. The capacitance is measured using the time to digital (TDC) converter integrated into the CC2652R1. The internal electronics charge the sensor with a constant current of 4.5 µA, while the real-time clock counts the charging time. Hence, the CC2652R1 measures how many clock periods (clock ticks) are necessary to charge the capacitance. The number of clock ticks is proportional to the capacitance size.

Measurement Setup

The sensor system was tested on the knee simulator developed in [5] to validate the measurement system in a lab environment, which also replicates the knee movements of a person.

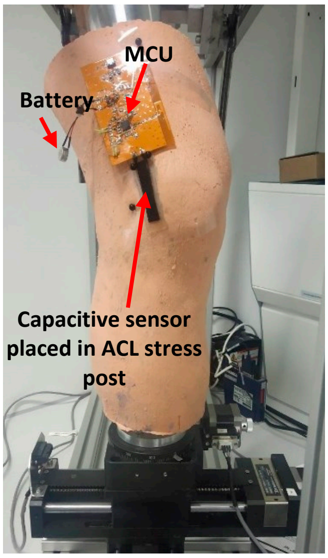

Fig. 3. Knee Simulator Setup

The whole sensor and the electronic are attached to the robotic leg in along the line of the anterolateral ligament [2] as shown in Fig. 3. The knee simulator is rotated from 10° to 45° insteps of 5° each. The degree of rotation is comparable to the real knee rotation scenario in a clinical setup.

The sensor measurements are taken for 3 cycles of rotation and the results are compared.

Results

The sensor is subjected to 3 cycles of motion. The measurements in each cycle have a good correspondence and are fitted with a second-order polynomial equation. The slight deviation in the curve towards larger angles is due to the disruption of the simulator when rotating. The R-square value of 0.993 is close to 1 which also proves a good correspondence of all the data with the fitting model. The data plots are shown in Fig. 4:

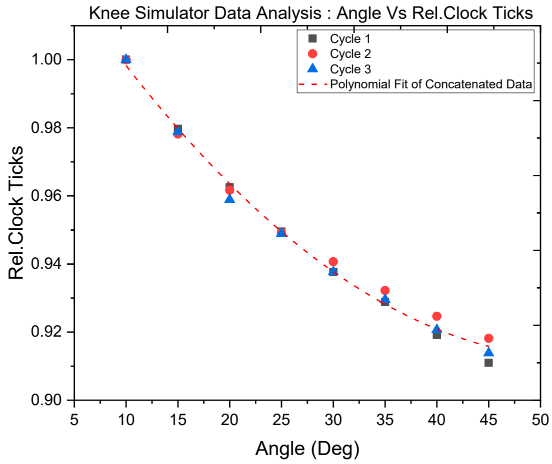

Fig. 4.Knee simulator data analysis.

From the data analysis, the sensor produces a reliable measurement along with the electronics.

The developed system satisfies the requirements of wearability, reproducible and repeatable. Therefore, this validation of data with the knee simulator paves the way towards clinical trials on patients with ligament instabilities.

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