PSU Reg. NO : 1701RD02

Year of Reg : 23.12.2016

A SYSTEMATIC APPROACH TO THE DESIGN AND DEVELOPMENT OF WEARABLE SENSOR FOR DETECTION OF ARTHRITIS USING GAIT PATTERN

ABSTRACT

Submitted by

ARUMUGARAJA M

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

FACULTY OF INFORMATION AND COMMUNICATION ENGINEERING

ANNA UNIVERSITY

CHENNAI 600 025

APRIL 2022

ABSTRACT

Arthritis is recognized as one of the most widespread articular diseases affecting a large population in the world and is the main cause of articular disability. Arthritis is a chronic disorder that can create problems in any bone joint. It arises frequently in the neck, thumb base, finger joints, hip, lower back, knee, and at the base of the big toes. In every bone joint, the cartilage covers the ends of each bone. Arthritis also results in lower limb trauma.

The normal gait of a human being is affected when the person is subjected to any injury or pain in the lower limbs. To reveal the underlying conditions of the subject and to aid in the diagnosis of the patient, the gait patterns of the subjects are captured and subsequently analysed. Gait analysis is one of the important tools used to deduce subtle and evident gait irregularities exhibited by the subject. The knee-pressure and foot-pressure distribution signals are collected from the individuals to identify the ones affected with knee pain.

The irregularities in gait often manifest as knee pain or physical discomfort experienced by the patient. Existing vision and floor sensor-based systems have the limitations of operational complexity and high cost that make them uncomfortable for individual use. Wearable sensors can be used to address this difficulty.

A Thermoplastic Polyurethane (TPU) - Carbon Nano Fiber (CNF) based nanocomposite piezoresistive pressure sensing film is developed by solution casting method. It is characterized by surface resistance, bulk resistance, impedance, and frequency dependence. The aim was to utilise the developed sensor to capture the pressure distribution around the knees during gait. Pressure sensing mechanisms are arranged in an appropriate knee cap utilising a TPU-CNF based nanocomposite piezoresistive (20% w/w) sensing

film with a bulk resistivity of 192Ω-cm in this research. The reliability of this arrangement for detecting the change in resistance owing to pressure fluctuation during knee movement is also examined. The voltage changes in various compressive stacking lab experiments indicated that this developed piezoresistive material has a wide range of applications. As a result, it can be efficiently used for signal acquisition applications in arthritis patient knee movement monitoring. TPU-CNF20 has been proven to be suitable for monitoring the gait of arthritis patients. It has a lower bulk resistivity (192 ± 6.5 Ω-cm) at the same time it has a higher linear fit of R^2=0.99306.

The developed flexible piezoresistive sensing films are simply sandwiched between two copper foil electrodes for improved conductivity in the experiments. In real-time, signals for four types of knee joint movements are collected: Knee extension, bend, half squat, and knee raise. Using statistical time-domain features, the main characteristics of these four movements are identified.

The data was collected from the TPU-CNF sensor, however, the subjects exhibited restricted movements. These limitations led to research interest in the design and development of insole embedded with 102 piezoelectric sensors to capture foot-pressure distribution images and to detect lower limb disorders. From the morphological analysis and the resistance response curve, a foot pressure sensor was developed at a lamination temperature of 120°C. The developed piezoresistive-based sensorized insole with excellent sensing applications was successfully used for acquiring the high-resolution pressure distribution profile.

The quality of these heat images is enhanced by a Hybrid Filter (RMSE=2.748 and PSNR=39.35) and a feature extraction technique is utilised on the enhanced foot pressure images for classification. The k nearest neighbours (KNN) learner model yields an accuracy of 99.4% in the detection

of knee pain. Gray level co-occurrence matrix (GLCM) based and pre-trained DNN based approaches are used for feature extraction. GLCM based feature extraction, the GLCM-Full & GLCM-HR approaches KNN learner model yielded an accuracy of 99.11%. GLCM-VR approach KNN learner model yielded an accuracy of 99.44%.

In the pre-trained deep neural network (DNN) based feature extraction, InceptionV3, VGG16, and VGG19 DNNs are involved. Inception V3 and VGG19 based approaches, the KNN learner model yielded an accuracy of 99.89%. In the VGG16 based approach, the KNN learner model yielded an accuracy of 99.83%.

The results show that the developed TPU-CNF based piezoresistive sensors and velostat based sensorized insole are the most suitable for analysing the gait pattern.