ENABLING THE VERSATILITY OF FLEXIBLE FERRO-ELECTRET NANO-GENERATORS: FROM ACOUSTICS TO BRAIN VIBRATIONS

By

Henry Manoj Dsouza

Advisor: Nelson Sepúlveda

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ABSTRACT

This dissertation presents the characterization and use of a flexible polypropylene-based FerroElectret NanoGenerator (FENG), a quasi piezoelectric device, across four different applications: loudspeaker, microphone, concussion detection, and brain vibration measurement. The first two applications focus on acoustical metrics that the FENG performed under various configurations and test conditions. As a microphone/loudspeaker, the relationship between sound output and electrical input is studied and found to be linear within the audible range, and up to 20 kHz. Ultrasonic frequencies (20 - 40 kHz) are also characterized. The influence of device shape and size on directivity was also studied. A theoretical model was developed, which was used to analyze and model the observed behavior. The spectral information of the output from a FENG-based microphone was compared with that of commercially available products.

For concussion detection, this work demonstrates the development of a flexible, self-powered sensor patch that can be used to estimate angular acceleration and angular velocity, which are two essential markers for predicting concussions. The device monitors the dynamic strain experienced by the neck through a thin, FENG device that produces a voltage pulse with a profile proportional to the applied strain. The intrinsic property of this device to convert energy between mechanical and electrical domains, along with its flexibility and $\sim 100 \ \mu$m thickness makes it a viable and practical device to be used as a wearable patch for athletes in high-contact sports. After processing the dynamic behavior of the produced voltage, a correspondence between the electric signal profile and the measurements from accelerometers integrated inside a human head and neck substitute was established. This demonstrates
the ability to obtain an electronic signature that can be used to extract head kinematics during a collision and create a marker that could be used to detect concussions. Unlike accelerometer-based current trends on concussion-detection systems, which rely on sensors integrated into the athlete's helmet, the flexible patch attached to the neck would provide information on the dynamics of the head movement, thus eliminating the potential of false readings from helmet sliding or peak angular acceleration.

Following up on the work related to brain injuries, the FENG was used to sense vibrations in a biofidelic brain upon blunt impact. In this work, the study of modality of deformations is highlighted. This study is carried out using two different approaches: Particle Image Velocimetry (PIV), and using FENG as an invasive flexible sensor in the phantom. Results show that the system has a natural mechanical frequency of $\sim 25$ oscillations per second, which was corroborated by both methods. The consistency of these results with previously reported brain pathology validates the use of either technique and establishes a new, simpler mechanism to study brain vibrations by using flexible piezoelectric patches. The visco-elastic nature of the biofidelic brain is validated by observing the relationship between both methods at two different time intervals, by using the information of the strain and stress inside the brain from the PIV and flexible sensor, respectively. A non-linear stress-strain relationship was observed and justified to support the same.

In the case of a microphone, concussion detection, and brain vibrations the FENG was configured as a sensor i.e. a stress was exerted on the FENG and its response was recorded and studied. In the case of loudspeaker, an electrical stimuli was applied to the FENG and its strain (actuation) was analyzed. This kind of versatility demonstrated by the FENG is a testament to the world of flexible sensors and transducers.