Indian Journal of Information Sources and Services
ISSN: 2231-6094 (P), Vol.13, No.2, 2023, pp.64-67

DOI: https://doi.org/10.51983/ijiss-2023.13.2.3862

IoT Integrated Accelerometer Design and Simulation for Smart Helmets

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(Received 20 November 2023; Accepted 27 November 2023; Available online 29 November 2023)

Abstract* - This article delves into the transformative potential of micro-electromechanical systems (MEMS) accelerometers, particularly their role in revolutionizing helmet safety. Accelerometers, ubiquitous in vehicle manufacturing, computer technology, and audio-video systems, play a crucial role in measuring acceleration. This work focuses on the design and simulation of a rotating accelerometer integrated into football helmets. The introduction of rotational acceleration addresses specific challenges in detecting and mitigating brain injuries that linear accelerometers may encounter. Additionally, the article explores the concept of piezoresistive football helmets, designed to resist force and reduce the impact of concussions. Piezoresistive helmets, designed to resist force and minimize the impact of concussions, when augmented with Internet of Things (IoT) capabilities can create a comprehensive smart safety solution. The incorporation of IoT sensors and connectivity into piezoresistive helmets enables real-time monitoring and data analysis of impact forces. This integration not only enhances player safety by providing immediate insights into potential risks but also opens avenues for injury prevention strategies. Leveraging COMSOL simulation software, this research not only conceives but also realizes the innovative integration of rotational accelerometers and piezoresistive materials in football helmet design, advancing safety standards in sports technology.
***Keywords:* MEMS, Piezoresistive, Concussion, Rotational Accelerometers**

I. INTRODUCTION

An electromechanical device that detects acceleration forces by static means, such as the steady force of gravity pushing at our feet, or by dynamic means, which are created by moving or vibrating the accelerometer. It took more than 15 years for micro-machined accelerometers to become common products for high-volume applications, even though the first micro-machined accelerometer was invented in 1979 at Stanford University [1]. Micromachined accelerometers are a technology that has a very high potential for commercial use and is extremely enabling. They give sensing that is resilient, small, and requires less power. It is common practice to integrate many sensors in order to achieve multi-axis sensing and obtain more precise data [2]. For example, if an accelerometer is positioned so that it is standing still on the surface of the Earth, it will be able to measure the acceleration that is brought about by the gravity of the Earth, which is roughly 9.81 m/s^2. Free fall, which is defined as falling towards the center of the Earth at a velocity of around 9.81 m/s^2, will cause an acceleration sensor to register a signal of zero [3].

The use of MEMS accelerometers in portable electronic gadgets and controllers for video games is becoming increasingly common with each passing year. There is a widespread use of these devices to either detect the position of the device or offer input for games [4, 5, 6]. The linear accelerometers that are used in football helmets have been selected as an example of an application within which linear accelerometers have minimal constraints.

The impact of a concussion is one of the factors that play a role in the decision of players to stop playing the game [7,8]. When a ball strikes an athlete, the brain sustains damage which is referred to as a concussion [9, 10, 11]. After reaching a specific limit, the linear accelerometer is unable to spin the head of a sportsman, which can also result in a concussion [12]. Estimates and simulations of rotating accelerometers are therefore performed to circumvent the variables. The determination of the degree of acceleration that results in brain damage may be of assistance in the decision-making process regarding prevention, diagnosis, and return to play [13,14]. In a significant proportion of field measurements, accelerometers affixed to the player's helmet are employed to assess the magnitude of acceleration experienced by the player.

Due to the purpose of helmets in mitigating head acceleration, the utilization of accelerometers affixed to the helmet may not provide an accurate representation of head acceleration [15]. The utilization of an intraoral device for assessing impact acceleration to the head has the potential to yield dependable measurements of accelerations in sports that do not involve helmet usage. Additionally, this approach may offer a more precise evaluation of the limits of brain acceleration in these particular activities [16]. The acceleration of the cranium is a result of the combined effects of linear and rotational acceleration upon impact with an external force.

As a result, accelerations lead to the generation of pressure gradients and tension within the soft tissue of the brain. Brain tissue can sustain injuries when the pressure gradients or forces exceed the tolerable limits of the brain tissue. Measuring the tissue-level response of the brain to impact in vivo poses significant challenges, making it exceedingly difficult to obtain direct measurements [17]. This research explores a groundbreaking approach to enhance safety in football helmets by seamlessly integrating two cutting-edge technologies: Internet of Things (IoT) and piezoresistive materials. By merging IoT sensors and connectivity with piezoresistive materials, this study aims to pave the way for the creation of a smart and responsive football helmet system.

The combination of these technologies would allow for real-time monitoring of impact forces and the immediate adjustment of the helmet's resistance to optimize protection [18, 19, 20]. The article delves into the simulation aspects of this integrated solution, highlighting the potential to revolutionize helmet design for improved player safety. Through COMSOL simulation, the research showcases the promise of this novel combination in mitigating head injuries and advancing the overall safety standards in contact sports. To accomplish the task of estimating the force, COMSOL simulation techniques have been applied. Furthermore, designs that are based on certain materials have been selected and explored.

II. DESIGN AND SIMULATION

For the purpose of developing and analyzing a rotating accelerometer within the framework of football helmet design, this research makes use of the varied possibilities that COMSOL Multiphysics offers. To be more specific, the application of normal force and solid mechanics are utilized to evaluate the effects of concussions. To determine force magnitudes, the utilization of piezoresistive materials, which are renowned for their lightweight and durable qualities, is of great assistance. The purpose of this study is to investigate the relationship between acceleration, impact force, and rotation of the accelerometer, which is an essential instrument for determining effective mass during impact. In addition, the integration of piezoresistive materials is being examined as a means of improving the accuracy of the diagnosis of concussion repercussions.

Under the assumption that the helmet is a sphere, the research investigates the influence of force on a number of different axes and modes of rotation, which is essential for comprehending the values of stress. In the process of calculating the total displacement (stress values), the force values of 10 (x), 50 (y), and 100 (z) have been applied to one side of the sphere as well as to the whole region of the sphere. Due to the fact that the force exerted on the helmet might be anywhere during the game, the linear accelerometer is unable to perform its function, which can result in a concussion. As a result, rotation has been taken into consideration. In a similar manner, the rotation has also been applied to the entire sphere; however, the force has been applied to all three axes, and the stress has been calculated.

A concentration on rotation is stressed as a means of compensating for the constraints of linear accelerometers in the context of dynamic gameplay settings. A number of different force and rotation values on a variety of axes are investigated in this study, which highlights the need of considering rotational dynamics in order to prevent concussions.

During the course of the research, a comprehensive analysis is carried out, during which the mode of rotation is changed in order to examine the influence of force distribution, with a specific emphasis placed on the Y-axis. Outer layer materials, more especially piezoresistive and piezoelectric substances, are applied in a strategic manner throughout the research project in order to reduce the intensity of force effects.

In addition, three various scenarios are investigated, each of which modifies the variables of force, rotation, and materials to ascertain the values of stress. The material composition is altered, with lead zirconate titanate (PZT) being applied to the outer layer and polydimethylsiloxane (PDMS) being applied to the sphere in the first example. In the second case, P-Silicon was put in place of PDMS. Both of these modifications were seen. By shedding light on the efficiency of various material modifications in improving helmet safety, the research provides valuable insight. The outcomes of the simulations are depicted in Figures 1 and 2. These demonstrate how intricate spinning accelerometers are and the function that they play in preventing concussions from being caused by football helmets utilizing the technology.

III. RESULTS AND DISCUSSION

There is a wide range of variation in both the amount of force and rotation that the accelerometer produces, and distinct findings have been made. According to the findings, the force acting on the Y-axis and rotation taking place along the same axis (clockwise) have a greater influence. As a result, the outer protective layer is designed, and the materials are altered according to the stress values that are acquired. The utilization of piezo-electric materials (PZT and PDMS) over piezo-resistive materials (P-Silicon) demonstrates a significant reduction in impact.

In conjunction with the application of force and rotation, the employment of PZT as the outer layer and PDMS as the inner layer results in stress values of 0.066 x 10^4 N/m^2 (maximum) and 0.063 x 10^4 N/m^2 (minimum). These stress values determine the maximum and minimum stresses, respectively. The employment of PZT as the outer layer and P-silicon as the inner layer, in conjunction with the application of force and rotation, results in stress values that range from 0.0764 x 10^4 N/m^2 (minimum) to 0.21 x 10^4 N/m^2 (maximum). The acceleration force and rotation of the accelerometer, in addition to the change in material, are displayed in Table I.

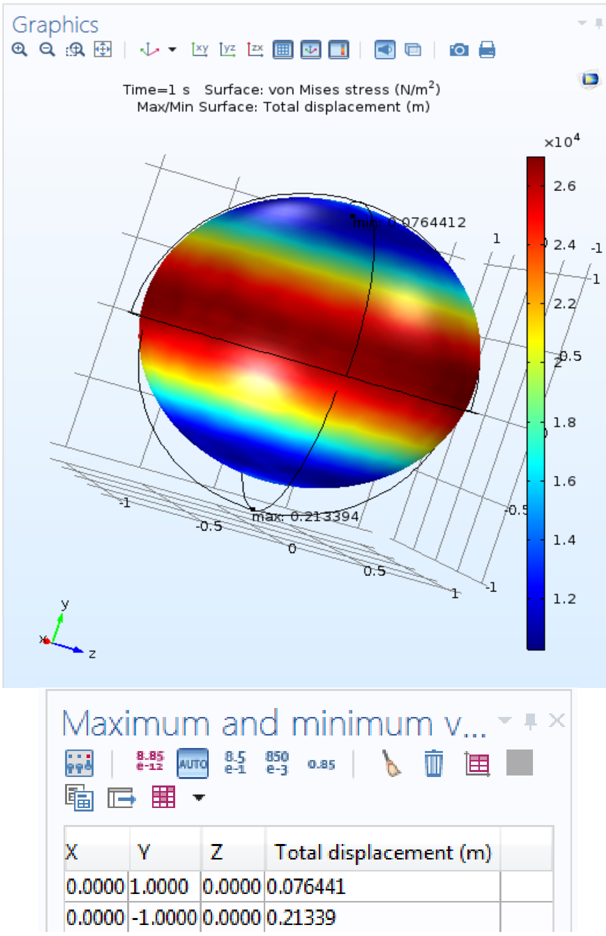

Fig. 1 Force -100(y axis) and rotation – clockwise (y axis)
Material: PZT and PDMS

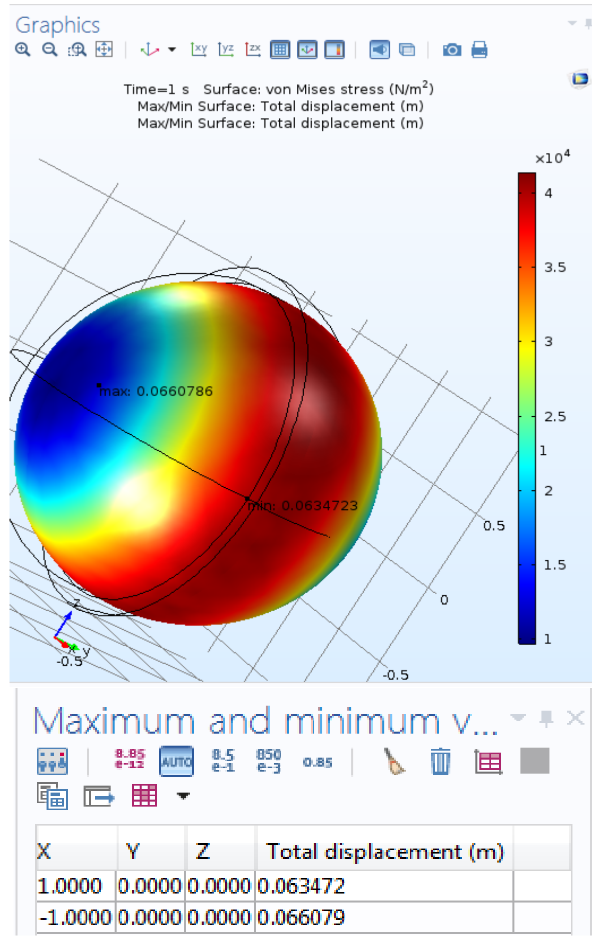

Fig. 2 Force -100(y axis) and rotation – clockwise (y axis)
Material: PZT and P- silicon

TABLE I TOTAL DISPLACEMENT WITH RESPECT TO ROTATION AND FORCE ALONG THE Y-AXIS, AS WELL AS MATERIAL VARIATION BETWEEN THE INNER AND OUTER LAYERS

Sl. No.	Force & Rotation		X- axis	Y-axis	Z-axis	Total Displacement
1	Force - Y axis Rotation- clockwise Material – PZT & PDMS	Max	0	1	0	0.0666
		Min	0	-1	0	0.063
2	Force - Y axis Rotation- clockwise Material – PZT & P-Silicon	Max	0	1	0	0.21
		Min	0	-1	0	0. 0764

These findings provide critical insights into the comparative effectiveness of these material combinations in mitigating impact forces on football helmets. The study systematically evaluates the stress distribution across the helmet structure, considering variations in force, rotation, and material composition. The outcomes contribute valuable data to the ongoing efforts in optimizing football helmet safety, with potential implications for the future development of advanced protective gear. Figures and visual representations accompany the detailed stress values, offering a comprehensive overview of the comparative performance of PZT/PDMS and PZT/P-Silicon configurations. Piezoelectric accelerometers are well-suited for measuring rapid changes in acceleration, making them suitable for impact and shock measurements. This capability is valuable in applications like crash testing and other impact studies.

IV. CONCLUSION

While there are several devices accessible for gathering head-impact data, the majority of peer-reviewed devices are helmeted and have mostly been employed in the context of football. The therapeutic value of these devices is constrained by their mistake rates and low generalizability. While real-time data collection offers a means of quantifying head-impact exposure, it is not appropriate to utilize linear accelerometers for diagnosing concussions. The rotating accelerometer has been considered, and the effects of force and rotation have been computed. The utilization of the COMSOL modeling tool in the design of a football helmet, incorporating a rotating accelerometer, piezoresistive material, and a piezoelectric material coating, demonstrates a reduction in the magnitude of force exerted on the helmet during impacts. The utilization of PZT as the outer layer and PDMS as the inner layer, in conjunction with the application of force and rotation, yields stress values of 0.066 x 10^4 N/m^2 (maximum) and 0.063 x 10^4 N/m^2 (minimum). The utilization of PZT as the outer layer and P-silicon as the inner layer, in conjunction with the application of force and rotation, yields stress values of 0.21 x 10^4 N/m^2 (maximum) and 0.0764 x 10^4 N/m^2 (minimum). These studies shed light on how well various material combinations reduce football helmet impact forces. Following the findings, the PZT/PDMS configuration exhibited a lower level of stress in comparison to the PZT/P-Silicon designs. Likewise, the aforementioned design may be effectively employed in practical contexts, such as the development of rotating accelerometers for football helmets, to mitigate the detrimental impact of concussions.

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