Progress in Medical Devices
eISSN: 2957-5478

Review Article https://doi.org/10.61189/871852usmbep

Applications of vibration sensors in medicine: Enhancing healthcare through innovative monitoring

Zine Ghemari

Electrical Engineering Department, Mohamed Boudiaf University of M'sila, 28000, Algeria

Corresponding author: Zine Ghemari.

Declaration of conflict of interest: None.

Received February 11, 2024; Accepted May 6, 2024; Published June 30, 2024

Highlights

- The article provides an overview of vibration sensors and their use in medical applications.
- Vibration sensors are used to monitor human movement, such as gait analysis and they can provide valuable data for assessing mobility, balance, and detecting abnormalities in movement patterns.
- The article explores how vibration sensors are integrated into wearable health devices, and these devices can monitor vital signs such as heart rate, respiratory rate, and sleep quality, providing continuous health monitoring.

Abstract

Recently, vibration sensors, initially confined to industrial use, have emerged as pivotal tools in medical practice. This article delves into their myriad applications within healthcare, underscoring their potential to reshape patient care paradigms. From wearable gadgets to cutting-edge medical equipment, the incorporation of vibration sensors holds promises to redefine patient monitoring, diagnostics, and therapeutic strategies. By integrating these sensors, healthcare professionals gain novel insights into physiological dynamics, ultimately improving patient outcomes. The integration of vibration sensors into medical practice not only enhances the accuracy and efficiency of health monitoring and diagnostics but also opens up new avenues for personalized medicine. As these technologies continue to evolve, they hold the promise of transforming healthcare delivery, making it more responsive, proactive, and patient-centric.

Keywords: Sensor, medical, therapeutic, diagnostics, application

Introduction

The incorporation of vibration sensors into medical devices represents a profound advancement in healthcare technology, ushering in a new era of innovation and capabilities [1]. Traditionally, vibration sensors have been primarily used in industrial applications, where they are utilized for detecting machinery faults and assessing structural integrity [2, 3]. However, the integration of these sensors into the healthcare domain signifies a significant shift from their conventional usage. This transformation marks a transformation in the pattern of technology application in medical field, opening up new avenues for improving patient care and advancing diagnostic capabilities [4-6].

One of the most notable developments in the utilization of vibration sensors in healthcare is their role in real-time monitoring and interpretation of physiological signals [7]. Previously, vibration sensors were confined to detecting mechanical vibrations in machinery, and now they are capable of capturing and analyzing subtle vibrations generated by physiological processes within the human body. These sensors can detect and measure a wide range of physiological events, including heartbeats, muscle contractions, respiratory movements, and even micro-movements associated with neurological activity [7].

The innovative applications of vibration sensors in healthcare are multifaceted and diverse. Wearable devices equipped with vibration sensors have emerged as powerful tools for the continuous, real-time monitoring of vital signs and physiological parameters [8-10]. These devices can track various metrics such as heart

Address correspondence to: Zine Ghemari, Electrical Engineering Department, Mohamed Boudiaf University of M'sila, P.O. Box 166, Ichbilya - M'Sila 28000, Algeria. E-mail: ghemari-zine@live.fr.

Table 1. Simulation parameters used to simulate heart rate

Define parameters	Values
Sampling Frequency (Hz)	100
Number of samples	1,000
Simulate sensor data	
Baseline heart rate (beats per minute)	75
Standard deviation	5
Add noise to simulate variability	
Noise amplitude (μm)	5

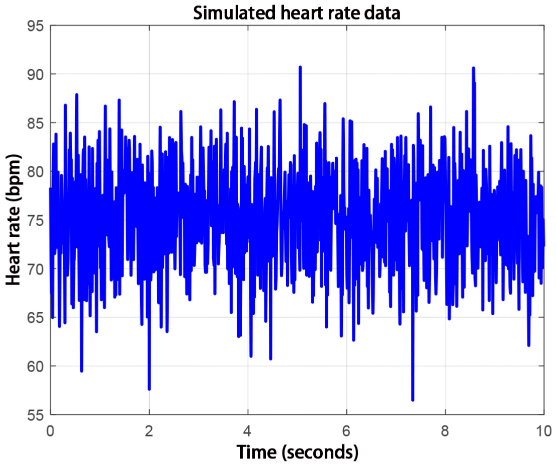

Figure 1. Simulated heart rate. bpm, beat per minute.

rate, respiratory rate, and activity levels, providing valuable insights into the wearer's health status and facilitating early detection of abnormalities or deviations from baseline values. Furthermore, vibration sensors can be integrated into medical implants or prosthetics to monitor their performance and functionality, ensuring optimal patient outcomes and enhancing the overall quality of care [11-13].

The integration of vibration sensors into medical devices holds immense potential for revolutionizing medical diagnostics and patient care. By enabling the collection of real-time physiological data, these sensors empower healthcare professionals with valuable information for making informed decisions and providing personalized treatment approaches [14-19]. The continuous monitoring capabilities of vibration sensors enable proactive healthcare interventions, allowing for early detection of health issues and timely interventions to prevent complications. Moreover, the data obtained from vibration sensors can be leveraged for advanced analytics and predictive modeling, facilitating the development of innovative diagnostic tools and treatment strategies [20].

This article summarizes the diverse applications of vibration sensors in healthcare, emphasizing their capacity to revolutionize patient care methodologies. From wearable devices to state-of-the-art medical apparatus, the integration of vibration sensors holds the promise of revolutionizing patient monitoring, diagnostics, and therapeutic approaches. Through the utilization of these sensors, healthcare providers stand to acquire fresh perspectives on physiological dynamics, culminating in improved patient outcomes.

Wearable health monitoring devices

Vibration sensors play a pivotal role in the development of wearable health monitoring devices. These sensors, when integrated into wearable gadgets, can capture subtle vibrations associated with physiological processes. The ability to monitor parameters such as heart rate, respiratory rate, and even muscle contractions provides a non-intrusive and continuous method for tracking health metrics [21].

Overall, the goal of creating a MATLAB program is to facilitate the development and testing of algorithms for wearable health monitoring applications. It allows researchers and developers to experiment with different data processing techniques, evaluate algorithm performance, and explore potential insights derived from sensor data.

To simulate different heart rate patterns or incorporate more sophisticated models in MATLAB, we use the parameters presented in **Table 1**, and the simulation results are shown in **Figure 1**.

Figure 1 provides a visual representation of simulated heart rate measurements, aiding in the interpretation and analysis of cardiovascular activity. The horizontal axis typically represents time. Each point or interval along the axis corresponds to a specific period, such as seconds, minutes, or hours. The vertical axis indicates heart rate values. It measures the frequency of heartbeats per unit of time, usually expressed in beats per minute or another appropriate unit. The line or plot in the graph represents the simulated heart rate data. Each point on the plot corresponds to a heart rate measurement recorded at a specific time. The pattern of the line reflects changes in heart rate over time.

The plot can reveal trends or patterns in the

Table 2. Simulation parameters used to simulate respiratory rate

Define parameters	Values
Sampling frequency (Hz)	1
Number of samples	3,600
Patient vital sign	
Heart rate mean (beats per minute)	75
Standard deviation	5
Respiratory rate mean (beats per minute)	12
Respiratory rate standard deviation (beats per minute)	2

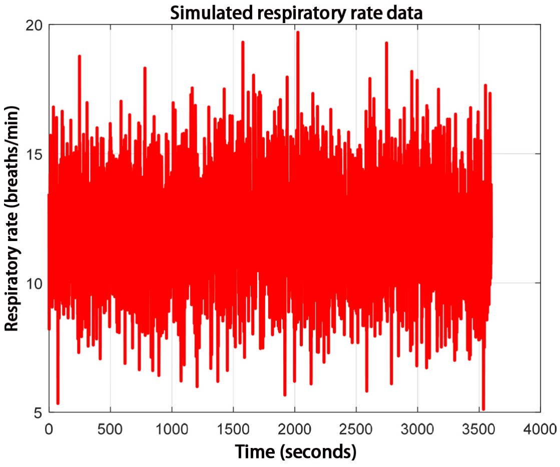

Figure 2. Simulated respiratory rate data.

simulated heart rate data, such as fluctuations in heart rate, periodic variations, or sudden changes indicative of physiological responses or abnormalities.

Researchers or healthcare professionals can analyze the simulated heart rate data to gain insights into cardiovascular health, monitor changes over time, or assess the effects of interventions. This analysis may involve identifying peak heart rates, calculating average heart rate values, or detecting irregularities in the heart rate pattern.

Remote patient monitoring

In the era of telemedicine, remote patient monitoring has become increasingly prevalent. Vibration sensors enhance this practice by enabling the collection of relevant health data without physical contact. From monitoring tremors in neurodegenerative disorders to assessing respiratory patterns in chronic conditions, remote patient monitoring with vibration sensors extends the reach of healthcare services [22].

Overall, creating a MATLAB program for remote patient monitoring involves generating synthetic patient data, processing the data to extract meaningful information, and visualizing the results to facilitate interpretation and decision-making by healthcare providers. The basic example below serves as a foundational step for developing more advanced monitoring systems that can track and analyze various aspects of patient health remotely.

To simulate respiratory rate in MATLAB, we use the parameters presented in **Table 2**, and the simulation results are shown in **Figure 2**.

Figure 2 represents a graphical depiction of simulated respiratory rate measurements over a specific period.

The line or plot in the graph represents the simulated respiratory rate data. Each point on the plot corresponds to a respiratory rate measurement recorded at a specific time. The pattern of the line reflects changes in respiratory rate over time.

Surgical navigation and robotics

Vibration sensors find their applications in surgical navigation systems and robotics. By detecting minute vibrations during surgical procedures, these sensors provide valuable feedback to surgeons [23]. This enhanced precision is particularly beneficial in delicate surgeries, contributing to reduced invasiveness and improved postoperative outcomes [23].

Creating a surgical navigation and robotics application in MATLAB involves integrating image processing, control algorithms, and possibly hardware interfacing. **Figure 3** introduces a basic example demonstrating a simple robotic arm control system for surgical navigation.

Figure 3 is a simulation of a straightforward 3-link robotic arm controlled to reach a target position in 3D space using a basic inverse kinematics approach. This example can be expanded by integrating more sophisticated control algorithms, implementing collision detection, incorporating real-time imaging feedback, or interfacing with actual robotic hardware for enhaced surgical precision.

Prosthetics and orthopedics

In the realm of prosthetics and orthopedics, vi-

Table 3. Simulation parameters used to simulate forces in prosthetic leg

Define parameters	Values
Acceleration due to gravity g (m/s^2)	9.81
Mass of the leg (kg)	5
Spring stiffness K (N/m)	1000
Time	0:0.01:5

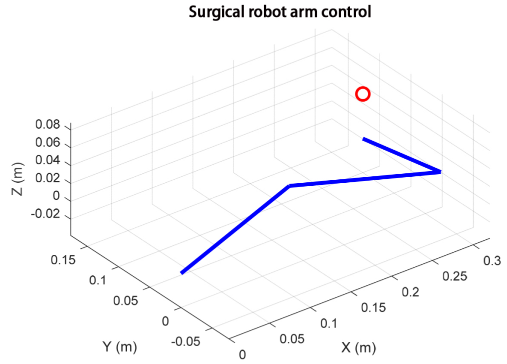

Figure 3. Surgical robot arm control.

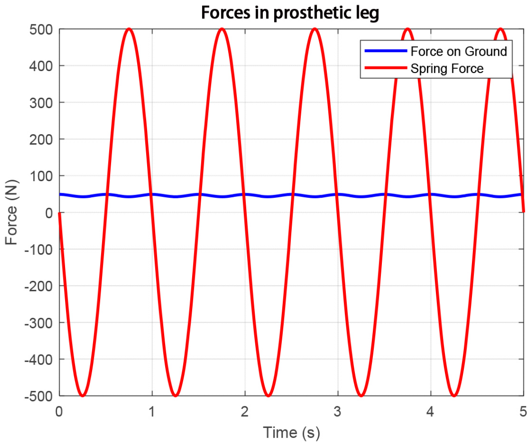

Figure 4. Forces in prosthetic leg.

bration sensors contribute to the development of intelligent devices. These sensors can detect changes in gait patterns, providing feedback to users and clinicians. Additionally, they play a role in monitoring the structural integrity of prosthetic limbs, ensuring optimal functionality and user satisfaction [24].

In practice, to incorporate more real-word models of leg movement and gait patterns for a more accurate simulation of walking motion. The following relationship illustrates leg angle as a function of time (simple harmonic motion):

$$\theta = \pi/6 \times \sin(2\times\pi \times t) \qquad (1)$$

With:
θ: leg angle
t: time (s)

The equation below allows to calculate the force exerted by the leg on the ground:

$$F_{leg} = m_{leg} \times g \times \cos(\theta) \qquad (2)$$

With:
F_{leg}: Force exerted by the leg (N)
m_{leg}: Mass of the leg (kg)

We use the following formula to calculate the force exerted by the prosthetic spring:

$$F_{spring} = -k_{spring} \times \sin(\theta) \qquad (3)$$

With:
F_{spring}: Force exerted by the prosthetic spring
k_{spring}: Spring stiffness k (N/m)

Creating a MATLAB program for prosthetics and orthopedics involves various tasks such as biomechanical modeling, motion analysis, and design optimization. Below is a basic simulation result of biomechanical modeling of a simple leg prosthetic.

To simulate forces in a prosthetic leg in MATLAB, we use the parameters presented in **Table 3**, and the simulation results are presented in **Figure 4**.

Figure 4 illustrates a specific presentation delineating the forces acting on a prosthetic leg. This visual aid is intended to complement textual discourse on forces exerted on a prosthetic leg during various activities.

Viewers or readers can interpret the information presented in the figure to gain insights into the mechanical behavior of prosthetic legs, potential challenges faced by users, and opportunities for improving design or rehabilitation strategies.

Rehabilitation and physical therapy

Vibration sensors are integral to rehabilitation and physical therapy practices [25]. They assist in assessing muscle activity, joint movement, and overall biomechanics during therapeutic exercises. This data-driven approach enhances the precision of rehabilitation protocols, leading to more personalized and effective treatment plans [26, 27].

The provided example in the context of MATLAB programming demonstrates a basic framework

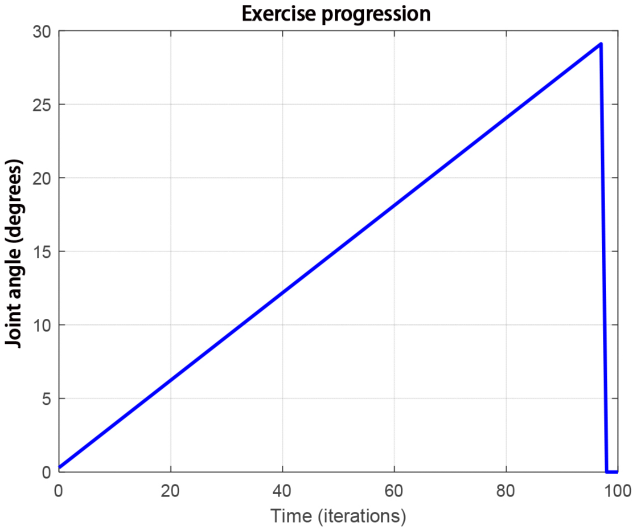

Figure 5. Exercise progression.

for exercise prescription and monitoring. It simulates an exercise session by gradually increasing the joint angle over time, monitoring the progression of the exercise, and visualizing the joint angle throughout the session. This basic example can serve as a foundation for developing more sophisticated rehabilitation programs using MATLAB's capabilities in biomechanical modeling, data analysis, and feedback integration (**Figure 5**).

Based on the assessment results in **Figure 5**, clear and achievable goals are established in collaboration with the individual. Goals may include improving cardiovascular health, increasing muscular strength and endurance, enhancing flexibility, weight management, injury prevention, or rehabilitation from injury or illness.

A personalized exercise program is developed to address the individual's goals, preferences, and limitations. The program typically includes a variety of exercises targeting different muscle groups and fitness components, such as cardiovascular exercise, resistance training, flexibility exercises, and neuromotor activities.

The principle of progressive overload is applied to gradually increase the intensity, duration, or complexity of exercises over time, continually challenging the body and fostering adaptation and improvement. Progression may involve adjusting resistance, repetitions, sets, exercise frequency, duration, or intensity level.

Conclusion

In conclusion, the incorporation of vibration sensors into medical devices represents a transformative shift in healthcare technology, with extensive implications for the diagnosis, treatment, and management of various medical conditions. By harnessing the power of vibration sensors to monitor and interpret physiological signals, healthcare professionals can unlock new insights into patient health and well-being, ultimately leading to improved outcomes and enhanced quality of care. As the field continues to evolve, the innovative applications of vibration sensors are poised to drive further advancements in medical diagnostics and patient care, shaping the future of healthcare in profound and impactful ways.

Author Contributions: Z. Ghemari contributed to the conceptualization, methodology, original draft writing, review and editing of the manuscript, and supervision.

Reference

[1] Bliznuks D, Cizovs J, Freimanis D, et al. Approaching Automated COPD Treatment Based on Markov Decision Process. 2023 IEEE 64th International Scientific Conference on Information Technology and Management Science of Riga Technical University (ITMS) 2023;1-5.
[2] Li C, Li J, Fang XL, et al. Application of a Method of Identifiying Instantaneous Shaft Speed from Spectrum in Aeroengine Vibration Analysis. 2022 Global Reliability and Prognostics and Health Management (PHM-Yantai) 2022;1-7.
[3] Zhao M, Shen X, Jiang F. Research on Mechanical Vibration Measurement Method Based on Event Camera. 2023 3rd International Conference on Energy Engineering and Power Systems (EEPS) 2023;528-532.
[4] S. GA, D B, Asha RM, et al. An IoT Enabled Smart Home Automation Using Augmented Reality in Computer Vision. 2023 International Conference on Self Sustainable Artificial Intelligence Systems (ICSSAS) 2023;1755-1761.
[5] Li S, Xiong Y, Zhou P, et al. mmPhone: Sound Recovery Using Millimeter-Wave Radios With Adaptive Fusion Enhanced Vibration Sensing. IEEE Trans Microwave Theory Tech 2022;70(8):4045-4055.
[6] Reguieg SK, Ghemari Z, Benslimane T. Extraction of the relative sensitivity model and improvement of the piezoelectric accelerometer performances. 2018 International Conference on Signal, Image, Vision and their Applications (SIVA) 2018;1-5.
[7] Ghemari Z, Chouaf F, Saad S. New Formula for the Piezoresistive Accelerometer Motion Acceleration and Experimental Validation. J Adv Manuf Syst 2017;16(01):57-65.
[8] Ghemari Z. Improvement of the piezoelectric sensor by the progress of the measurement accuracy. IEEE International Conference

on Smart Materials and Spectroscopy (SMS'2018) 2018.
[9] Ghemari Z, Belkhiri S. Mechanical Resonator Sensor Characteristics Development for Precise Vibratory Analysis. Sens Imaging 2021;22(1):40.
[10] Ghemari Z, Saad S. Reducing the Measurement Error to Optimize the Sensitivity of the Vibration Sensor. IEEE Sens J 2014;14(5):1527-1532.
[11] Khan NU, Ahmad S, Janjua MM, et al. The Design of Vibration Nomograph for the Vehicle Vibrations Affecting Man. 2022 Advances in Science and Engineering Technology International Conferences (ASET) 2022;1-7.
[12] Alamro H, Marzouk R, Alruwais N, et al. Modeling of Blockchain Assisted Intrusion Detection on IoT Healthcare System Using Ant Lion Optimizer With Hybrid Deep Learning. IEEE Access 2023;11:82199-82207.
[13] Ghemari Z, Belkhiri S, Saad S. Improvement of the Relative Sensitivity for Obtaining a High Performance Piezoelectric Sensor. IEEE Instrum Meas Mag 2023;26(4):49-56.
[14] Okada T, Isobe M, Kosaka T, et al. Study on Electric Motor Vibration Suppression by Active Dynamic Vibration Absorber. 2023 IEEE International Electric Machines & Drives Conference (IEMDC) 2023;1-7.
[15] Yan H, Zhang C, Wang G. Experimental Study on Dual-channel Active Control Method for Transverse Vibration of Ship Propulsion Shaft System. 2023 7th International Conference on Transportation Information and Safety (ICTIS) 2023;1353-1356.
[16] Ghemari Z. Enhancement of the vibratory analysis technique by the accelerometer characteristics evolution. The 7th International Conference on Control Engineering & Information Technology 2019.
[17] Ghemari Z, Belkhiri S, Saad S. A capacitive sensor with high measurement accuracy and low electrical energy consumption. Appl Phys 2023;129(5):362.
[18] Hao C, Xinyu D, Ling L, et al. Test and Analysis of Acoustic and Vibration Characteristics of Transformer in Winding and Iron Core Loose. 2023 IEEE 3rd International Conference on Power, Electronics and Computer Applications (ICPECA) 2023;1644-1647.
[19] Wang B, Zhang H, Cao M, et al. Parameter analysis and experimental verification of dynamic vibration absorption design for transformer tank wall. 2022 7th Asia Conference on Power and Electrical Engineering (ACPEE) 2022;830-837.
[20] Wang Y, Xia Z, Xie R. Vibration control technology of ship transmission based on machine learning. 2022 International Conference on Artificial Intelligence in Everything (AIE) 2022;580-584.
[21] Izhar M, Naqvi SAA, Ahmed A, et al. Enhancing Healthcare Efficacy Through IoT-Edge Fusion: A Novel Approach for Smart Health Monitoring and Diagnosis. IEEE Access 2023;11:136456-136467.
[22] Padmanaban K, Sarojini R, Ramalingam S, et al. LoRA-IoT based Intelligent Healthcare Device for Physically Challenged People in Hospital Application using Artificial Intelligence. 2022 4th International Conference on Circuits, Control, Communication and Computing (I4C) 2022;481-485.
[23] Raj A, Sharma S, Saluja P, et al. Seamless Live Ambulance Booking System with Patient Health Monitoring: Enhancing Emergency Care. 2023 International Conference on Electrical, Electronics, Communication and Computers (ELEXCOM) 2023;1-6.
[24] Gupta M, Shamsher S, Thirumalaisamy M, et al. Real time interaction-based Healthcare monitoring during Medical Emergencies with Internet of Things. 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE) 2022;915-923.
[25] Azmin A, Abdullah S, Rahiman W. Parametric Assessment of Communication Protocol for Evaluating the Efficacy of Real-Time Healthcare Data Transmission System. 2023 IEEE 13th International Conference on Control System, Computing and Engineering (ICCSCE) 2023;62-67.
[26] Zaydi H, Bakkoury Z. 4-Lead ECG Monitoring for Cardiac Care: Advancing Healthcare with Innovative Use of Connected Watches. 2023 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME) 2023;1-6.
[27] Ezhilarasi M, Kumar A, Shanmugapriya M, et al. Integrated Healthcare Monitoring System using Wireless Body Area Networks and Internet of Things. 2023 4th International Conference on Innovative Trends in Information Technology (ICITIIT) 2023;1-5.