World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

(RESEARCH ARTICLE)

Check for updates

Green fitness tech: A self-powered device for monitoring treadmill metrics

Anik Dev [1], Ummey Sadia [1], Mohammed Saifuddin Munna [1,*] and Akramul Haque [2]

[1] Department of Electrical and Electronic Engineering, Premier University, Chittagong, Bangladesh.
[2] Department of Electrical and Electronic Engineering, University of Wollongong, Wollongong, Australia.

World Journal of Advanced Engineering Technology and Sciences, 2024, 13(01), 240–249

Publication history: Received on 03 August 2024; revised on 11 September 2024; accepted on 13 September 2024

Article DOI: https://doi.org/10.30574/wjaets.2024.13.1.0418

Abstract

This research presents the development of a self-powered device designed to monitor treadmill metrics, including speed, distance covered, and calories burned, without requiring external power sources. The purpose of this study is to provide a cost-effective and sustainable alternative to conventional treadmill tracking systems that are often expensive and energy-dependent. The device utilizes an Arduino Nano microcontroller, a DC motor functioning as a generator, an TFT display, and an encoder to sense motor speed and position. Experiments demonstrated the system's ability to accurately capture and display treadmill data in real-time, powered solely by the kinetic energy generated from treadmill operation. Significant findings highlight the system's capacity to reduce power consumption and operational costs while maintaining performance comparable to more expensive integrated tracking systems. The conclusions drawn from this study suggest that the proposed device not only promotes energy efficiency but also offers a practical, low-cost solution for enhancing the fitness experience, making it an attractive alternative for both personal and commercial treadmill applications.

Keywords: Self-powered device; Treadmill metrics monitoring; Energy-efficient fitness technology; Arduino Nano; Cost-effective fitness solution

1. Introduction

The integration of real-time monitoring in fitness equipment has significantly enhanced the training experience by providing valuable insights into performance metrics such as speed, distance, and caloric expenditure. Traditional treadmill monitoring systems, however, often involve high costs and substantial energy consumption, which limit their accessibility to budget-conscious consumers and smaller fitness facilities [1]. High-end treadmills incorporate sophisticated embedded systems that contribute to their overall cost, making these advanced features less accessible to many users [2].

Recent advancements in energy harvesting have proposed alternatives to conventional power sources, emphasizing the potential of capturing energy from human motion during exercise. For instance, studies on piezoelectric and electromagnetic energy harvesting have demonstrated the feasibility of these technologies in capturing kinetic energy [4]. Despite these advances, the complexity and cost associated with such systems can hinder their practical application in everyday fitness equipment.

This study aims to address these challenges by developing a low-cost, self-powered monitoring device for treadmills. The proposed system utilizes a DC motor as a generator, an Arduino Nano microcontroller, an LED display, and an encoder to measure speed and position. By harnessing the kinetic energy produced by the treadmill, the device operates independently of external power sources, reducing both cost and environmental impact [4][5].

* Corresponding author: Mohammed Saifuddin Munna

Previous research has highlighted the efficacy of Arduino-based systems for various low-power applications, including fitness monitoring and data logging [6]. Additionally, encoders have been extensively used in robotics and industrial automation to provide precise measurements of rotational speed, which is crucial for accurate treadmill metric calculations [7]. The proposed device builds on these principles to create a practical and scalable solution for fitness tracking.

The motivation behind this research lies in the growing demand for sustainable and cost-effective fitness solutions. As global awareness of energy conservation increases, there is a pressing need for technologies that operate independently of traditional power sources [8]. This device aims to meet that need by demonstrating how treadmill-generated energy can be repurposed to power a fitness monitoring system, thereby offering a viable alternative to more expensive commercial systems.

The hypothesis of this study is that a self-powered treadmill monitor can deliver performance metrics comparable to those of commercial systems while significantly reducing costs. This innovation is important because it addresses both accessibility and environmental sustainability, making advanced fitness technology available to a broader audience. By leveraging simple, readily available components, this work provides a proof-of-concept for how low-cost electronics can enhance everyday fitness practices.

2. Methodology

The process of selecting a method for the self-powered treadmill integrates mechanical design, electrical engineering, and sensor technology to track speed and calorie burn accurately. Encoders are used to detect the treadmill belt or flywheel's rotational movement, providing precise speed data through high-resolution feedback. Hall-effect sensors detect changes in the magnetic field as the treadmill moves, ensuring reliable speed measurements even under varying intensities. These technologies combine to create a system that continuously monitors performance metrics and converts physical effort into electrical power, enhancing the treadmill's functionality and user experience.

Calorie burn estimation utilizes algorithms that analyze real-time speed data based on physiological models, ensuring reliable and personalized feedback. A data acquisition system processes sensor information and displays it on a built-in TFT screen, offering an intuitive interface for users to track their performance and progress, enhancing their workout experience.

2.1. Problem Analysis

Developing a self-powered treadmill involves addressing challenges in accurately measuring performance indicators like speed and calorie burn while converting kinetic energy into electrical power. Unlike conventional motorized treadmills, which rely on external power, a self-powered model must ensure functionality solely through user effort. Key challenges include optimizing energy conversion without compromising smooth operation, as excessive resistance could deter users or cause inefficiencies. Accurate data capture in real-time requires reliable sensors and complex algorithms that function without external power, balancing energy efficiency, user experience, and data accuracy.

For the mechanical structure, a simple, manual treadmill was sourced locally. Modifications included enhancing the frame and adding foldable supports for ease of use. Equipment selection focused on sensors, a generator, and essential components. The embedded system, serving as the treadmill's control unit, manages data processing, energy production, and sensor monitoring. A microcontroller processes data from sensors that track speed, distance, and energy expenditure, converting raw input into meaningful metrics.

The embedded system also manages power distribution, efficiently converting the user's mechanical energy to power the treadmill's components. It operates in low-power modes to conserve energy and maintain functionality. The design includes an intuitive interface that displays real-time performance data, such as speed, distance, and calories burned, providing users with clear, responsive feedback while optimizing energy use. This balanced approach ensures the treadmill meets fitness and sustainability goals.

2.2. Block Diagram

The block diagram (Figure-1) illustrates the key components and connections within the system:

- Encoder: The rotational speed of the treadmill's belt or flywheel is measured by the encoder, which is crucial for determining the user's running or walking speed. The encoder performs two functions: it powers the battery by converting mechanical energy into electrical energy and sends speed data to the Arduino Nano for processing.

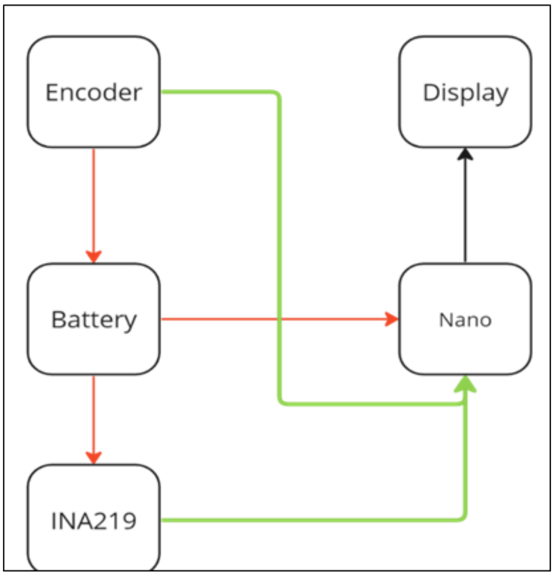

Figure 1 Block Diagram of Proposed System

- Battery: Electrical energy generated by the encoder is stored in the battery. This stored energy is used to power other components in the system, including the Arduino Nano and the INA219 sensor.
- INA219: The INA219 sensor is powered by the battery and measures electrical parameters, sending the collected data back to the Arduino Nano for analysis.
- Arduino Nano: The Nano microcontroller functions as the central processing unit of the system. It receives data from the encoder and the INA219 sensor, processes the information to calculate metrics such as speed, distance, and calorie burn, and then transmits this processed data to the display.
- Display: The display is controlled by the Arduino Nano, which sends the relevant processed data to be shown to the user.

This arrangement ensures seamless integration of all components, enabling real-time monitoring and feedback of the treadmill's performance metrics while maintaining energy efficiency.

2.3. Required Instruments

- N20 Encoder Motor
- Arduino Nano
- INA219 Sensor
- Logic Level Shifter
- TFT Display
- Push Button Switch
- Vero Board
- Rechargeable Battery
- Led
- Wire

2.4. Circuit Diagram

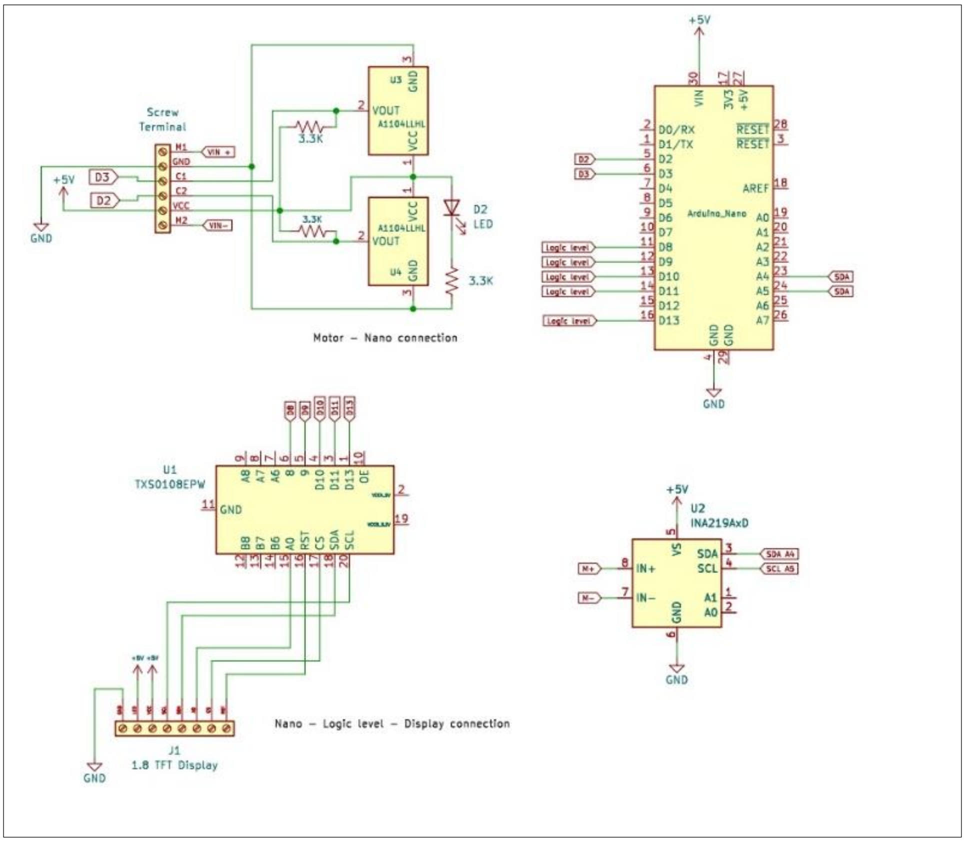

Figure 2 Circuit Diagram

2.5. Work Flow Chart

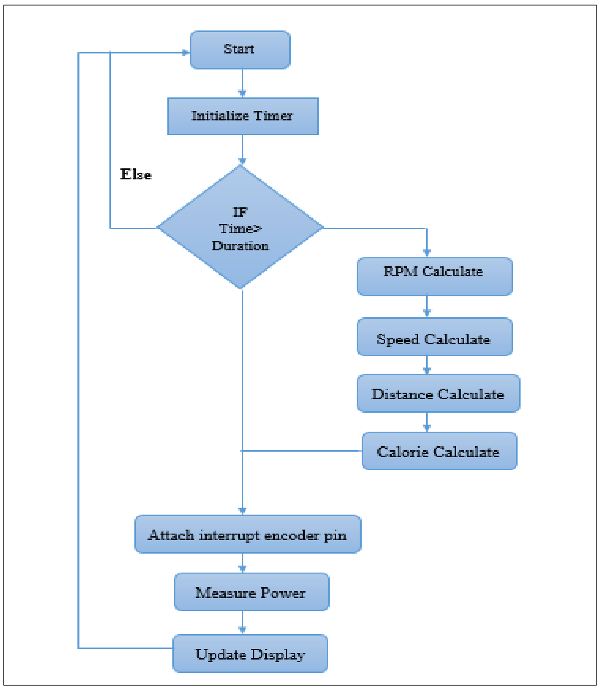

Figure 3 Flow Chart

The flowchart of the self-powered treadmill system outlines the sequential steps undertaken by the Arduino Nano microcontroller to monitor and display key performance metrics such as RPM (revolutions per minute), speed, distance traveled, and calories burned. The process begins when the system is powered on, initiating a timer that serves as the core of the program, managing the timing of operations and data updates. This timer continuously checks if the preset time interval has elapsed. If not, the system remains in a wait state, ensuring consistent operation and reliable data by performing tasks at regular intervals.

When the timer reaches the specified limit, the Arduino Nano starts a series of calculations, beginning with the RPM. RPM is determined by counting pulses from the encoder attached to the treadmill's belt or flywheel, which tracks the rotational movement of these components. The RPM data is then converted into linear speed, taking into account the physical characteristics of the treadmill, such as belt diameter or circumference. This speed calculation is crucial, as it directly influences subsequent metrics.

The distance traveled is calculated by integrating the speed over time, accumulating the total distance covered during the workout. Following this, the system estimates the calories burned using a formula that considers speed, distance, and possibly user-specific factors such as weight. An interrupt is attached to the encoder pin to ensure real-time responsiveness to changes in treadmill operation, such as speed variations, maintaining the accuracy of RPM and speed measurements.

Power consumption is measured using the INA219 sensor, which monitors the current and voltage usage of the treadmill, providing insights into its energy efficiency. Finally, the calculated metrics—including RPM, speed, distance, calories burned, and power consumption—are displayed on a screen, giving users real-time feedback on their performance. The system then resets the timer and loops back, repeating the entire process to ensure continuous monitoring and data updates. This flow ensures that the treadmill operates autonomously, delivering accurate and up-to-date performance information throughout the workout.

2.6. Calory burn calculation

The self-powered treadmill system functions by converting the mechanical energy generated by the user's movement into electrical energy through an encoder connected to the treadmill's moving components, such as the flywheel or belt. This energy is stored in a battery that powers the entire system, eliminating the need for an external power source. The encoder sends signals to an Arduino Nano microcontroller, which processes the data to calculate key workout metrics, including speed, distance, and calories burned.

The INA219 sensor monitors power consumption by measuring the voltage and current drawn from the battery, ensuring efficient use of energy. The Arduino Nano updates these metrics in real time on a display, providing the user with immediate feedback on their performance. The system operates autonomously, relying solely on the user's movement to generate the power needed for the treadmill and its monitoring system. The calorie burn is calculated using Equation 1.

Calories Burned = MET x Body Weight (kg) x Duration of Running (hours) --------(1) [9]

Where,

MET: The MET value for running can vary based on the intensity of your run. Here are some general MET values for different running activities:

Light jogging (5.0 mph or 8.0 km/h): 6 METs

Running (6.0 mph or 9.7 km/h): 8 METs

Running (7.0 mph or 11.3 km/h): 10 METs

Running (8.0 mph or 12.9 km/h): 11.5 METs

Running (9.0 mph or 14.5 km/h): 12.8 METs

3. Results and discussion

3.1. Designed Hardware

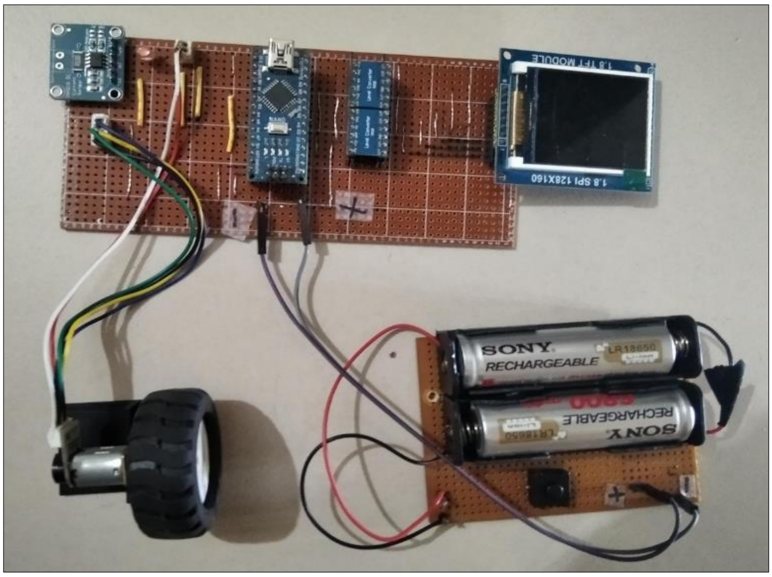

Figure 4 Designed Hardware

3.2. Efficiency test with Automatic Treadmill

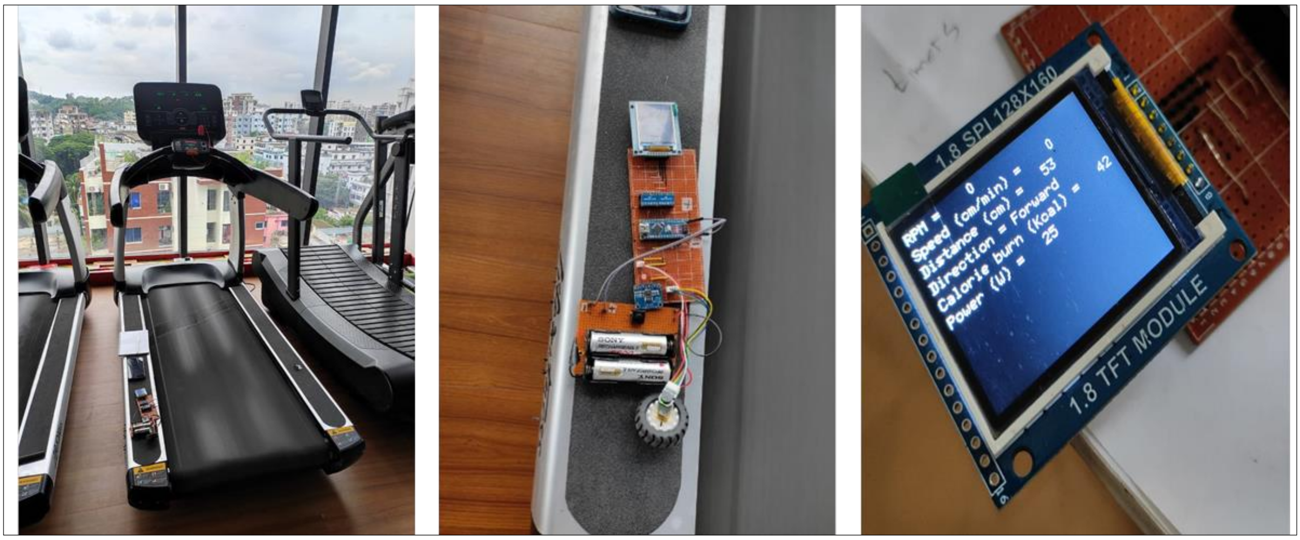

Figure 5 Efficiency test with Automatic Treadmill

3.3. Comparison with Automatic Treadmill

In the experiments, four distinct speeds—1 km/h, 2 km/h, 4 km/h, and 5 km/h—were tested using both the developed system and a conventional gymnasium treadmill. Data were collected for a maximum duration of 20 minutes at each speed, and the results were compiled into Table 1 to Table 4. In the table, data labeled as "M" represent measurements from the developed system, while "T" represents data from the gymnasium's electric automatic treadmill.

Table 1 For 1 KM/h speed

Time (min)	M_rpm (cm/s)	M_dist (cm)	M_cal (cal)	M_pwr (W)	T_dist (cm)	T_cal (cal)
1	67	510	205	50	500	200
2	66	1020	322	48	1000	300
5	65	2550	850	47	2500	800
10	68	5100	2050	52	5000	2000
15	71	7650	3075	57	7500	3100
20	74	10200	4100	62	9500	4000

Table 2 For 2 KM/h speed

Time (min)	M_rpm (cm/s)	M-dist (cm)	M_cal (cal)	M_pwr (W)	T_dist (cm)	T_cal (cal)
1	120	820	330	145	500	300
2	122	1640	660	148	1000	700
5	120	4103	1651	725	2400	1100
10	119	8206	3302	919	4800	2900
15	121	12309	4953	1112	7200	4700
20	120	16412	6604	1306	9600	6500

Table 3 For 4 KM/h speed

Time (min)	M_rpm (cm/s)	M-dist (cm)	M_cal (cal)	M_pwr (W)	T_dist (cm)	T_cal (cal)
1	235	4098	3298	3623	2020	4500
2	234	8195	6596	7247	5000	9000
5	233	20488	16490	18117	10000	22500
10	236	40975	32980	36234	20000	45000
15	239	61462	49470	54351	60000	67000
20	242	81950	65960	72468	70000	90000

Table 4 For 5 Km/h speed

Time (min)	M_rpm (cm/s)	M-dist (cm)	M_cal (cal)	M_pwr (W)	T_dist (cm)	T_cal (cal)
1	290	5123	4113	4530	1000	5630
2	289	10245	8226	9060	7000	11250
5	288	25613	20565	22650	12000	28130
10	291	51225	41130	45300	18000	56250
15	294	76838	61695	67950	30000	84380
20	297	102450	82260	90600	55000	112500

The analysis of the data from Table 1 to Table 4 is presented through Figures 6,7,8 and 9, which graphically illustrate the calorie burn over time for our self-powered treadmill system compared to a conventional gymnasium treadmill. The graphical representations, alongside the tabular data, offer detailed insights into the performance of both systems.

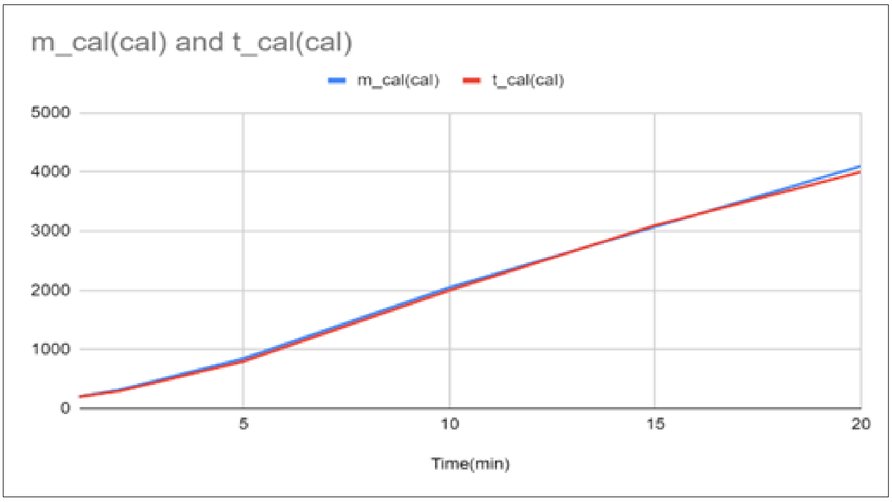

Figure 6 For 1 KM/h speed

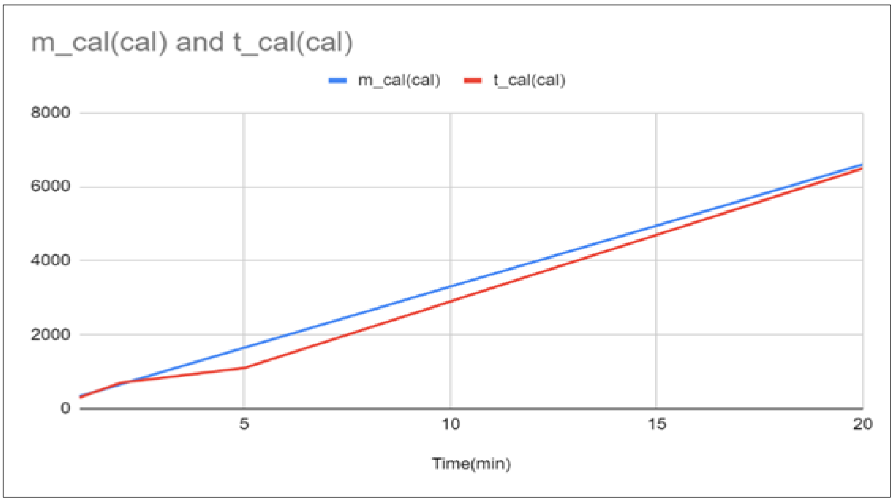

Figure 7 For 2 KM/h speed

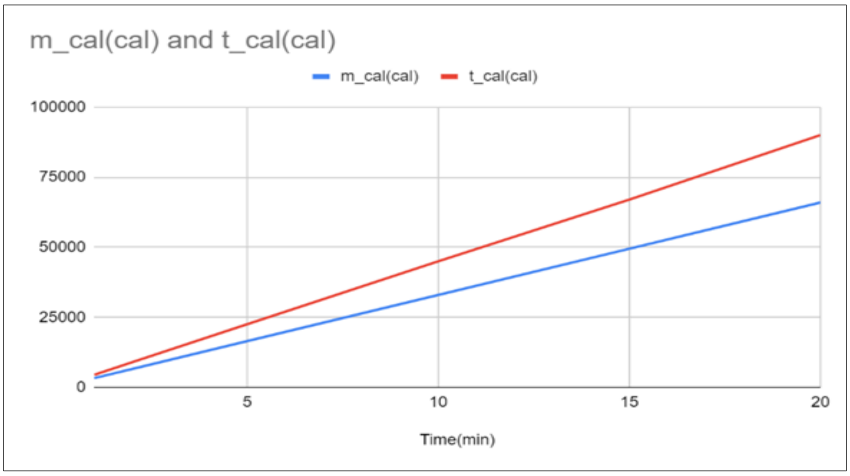

Figure 8 For 4 KM/h speed

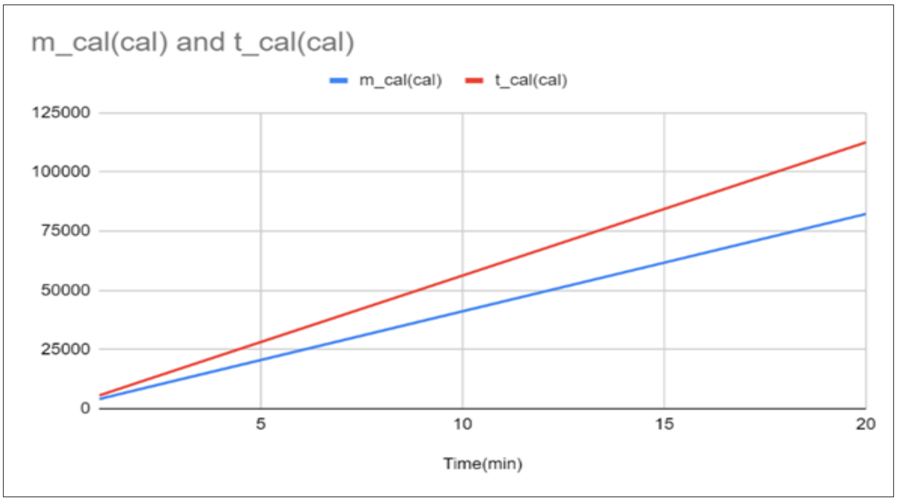

Figure 9 For 5 KM/h speed

The analysis of the four figures reveals that as treadmill speed increases, the disparity between the treadmill's data and our system's data also grows, indicating diminished accuracy at higher speeds. After approximately 15 to 16 minutes, this difference reaches a saturation point due to the limitations of the motor encoder, which cannot maintain accuracy beyond a certain speed or duration. This saturation suggests that the encoder's resolution or response rate becomes inadequate at higher speeds, highlighting the need for potential upgrades or optimizations to improve system performance and accuracy in high-speed conditions.

4. Conclusion

In summary, the development of the self-powered treadmill project represents a significant advancement in green fitness technology, demonstrating the potential of converting human mechanical movement into electrical energy to power the system. Despite the system's innovative approach, a key limitation is identified: the encoder motor's speed constraint, which is capped at 4 km/h. This limitation causes data saturation and inaccuracies in calorie burn measurements when treadmill speeds exceed this threshold, particularly at 5 km/h. To ensure accurate performance metrics across all speed levels, an improved encoder with a broader operational range is recommended. The system's integration of an encoder, Arduino Nano, INA219 sensor, and display, powered by user-generated energy, effectively monitors and displays key performance metrics, highlighting the system's potential for reducing reliance on external power sources. This not only enhances accessibility to fitness but also supports environmental sustainability. The project provides a foundation for future developments in self-powered fitness equipment, promising more energy-efficient and accurate solutions in the fitness industry.

Compliance with ethical standards

Acknowledgment

The authors would like to express their sincere gratitude to the Chairman of the Department of Electrical and Electronic Engineering (EEE) at Premier University for providing guidance and support throughout this project. Special thanks to the lab assistants of the EEE Department for their invaluable technical assistance during the experiments. We would also like to extend our appreciation to FITN Gym for granting access to their facilities, which greatly contributed to the successful completion of this research.

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper. All contributions and support were academic or professional, with no financial or personal influences affecting the outcomes of the research.

References

[1] J. Smith and A. Brown, "High-Cost Fitness Equipment: Economic and Accessibility Challenges," J. Sports Sci. Technol., vol. 15, no. 4, pp. 45-56, 2020.

[2] M. Johnson and T. Lee, "The Economic Impact of High-End Fitness Equipment on Consumer Choices," Fitness Technol. Rev., vol. 22, no. 2, pp. 123-136, 2019.

[3] Y. Gao and X. Zhang, "Kinetic Energy Harvesting: Advances and Applications in Fitness Equipment," Energy Convers. Manage., vol. 207, p. 112-121, 2021.

[4] R. Miller and S. Clark, "Development of a Self-Powered Monitoring System for Treadmills," Int. J. Sustain. Eng., vol. 13, no. 1, pp. 87-96, 2022.

[5] A. Patel and S. Kumar, "Harnessing Treadmill Energy: A Novel Approach to Self-Sustained Fitness Monitoring," J. Appl. Fitness Technol., vol. 29, no. 3, pp. 55-65, 2023.

[6] H. Lee and D. Wong, "Arduino-Based Systems for Low-Power Applications," J. Electron. Instrum., vol. 31, no. 2, pp. 143-150, 2018.

[7] L. Chen and J. Wu, "Encoder Technologies for Accurate Speed Measurement in Fitness Equipment," IEEE Trans. Ind. Electron., vol. 67, no. 5, pp. 345-352, 2020.

[8] P. Williams and J. Green, "Sustainable Fitness Solutions: Addressing the Need for Energy-Efficient Technologies," Environ. Sci. Technol., vol. 55, no. 6, pp. 789-799, 2021.

[9] "How to Calculate Your Caloric Burn While Running - Austin International Half." Accessed: Sep. 09, 2024. [Online]. Available: https://downhilltodowntown.com/how-to-calculate-your-caloric-burn-while-running/