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Self-Powered Keyboards: Utilizing Piezoelectric Technology and Hybrid Energy for Sustainable Innovation

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Abstract

This study investigated the potential of piezoelectric technology and hybrid energy in designing self-powered keyboards to improve energy efficiency in the digital age. Addressing a research gap in hybrid charging systems, the study focused on combining piezoelectric and solar technologies for sustainable energy solutions. Using a quasi-experimental design, the researchers measured keystroke energy output, typing speed, and accuracy to assess the performance of a Tenkeyless (TKL) mechanical keyboard (RK87 with Cherry MX Red switches) modified for energy harvesting. Factors such as key shape, material, and layout were analyzed to determine their influence on energy output. Data were collected through controlled experiments, which measured energy captured during typing based on typing speed, force, and patterns. Salient findings revealed that typing force and frequency significantly impacted energy harvesting. Heavier and repeated presses produced higher voltage outputs, with repeated heavy presses over shorter durations yielding the optimal balance between voltage and current. However, prolonged use resulted in diminishing current generation, indicating potential limitations in efficiency. The results confirmed the feasibility of piezoelectric keyboards as a sustainable energy solution, emphasizing the importance of design optimization and material durability for improved quality for users. The study recommended enhancing piezoelectric element responsiveness, using efficient materials, incorporating user feedback mechanisms, and integrating hybrid energy systems to maximize energy output. This research contributed to advancing sustainable innovation in digital technologies, offering environmentally friendly alternatives for energy consumption.

Keywords: Hybrid System, Energy Harvesting, Piezoelectric, Keyboards

Introduction

In the current digital age, energy plays a significant role in society by enabling various technological advancements and improving overall quality of life. Energy dispatch and allocation are optimized through energy digital transformation, leading to more sustainable energy practices (An, 2024) [4]. Moreover, the integration of digital technologies enhances energy management strategies, such as maximizing the self-consumption of renewable energy sources and reducing reliance on traditional power grids (Martín *et al*., 2022) [17].

The rapid increase of digital devices and the digitalization of society have led to increased energy consumption, impacting both society and the devices themselves. With the growing prevalence of digital technologies in various aspects of life, there is a corresponding rise in energy demand (Thanh *et al*., 2022). This surge in energy consumption creates bad environmental degradation, increases electricity usage, and contributes to carbon emissions (Arabi, 2023; Madlener *et al*., 2021). For example, the expanding production and consumption activities facilitated by digital technologies contribute to higher energy demands and worsen environmental deterioration (Thanh *et al*., 2022). Moreover, the usage of digital devices, such as laptops, smartphones, and IoT products, has been linked to a significant increase in energy consumption over the years (Druilhe *et al*., 2013; Manz *et al*., 2021) [11, 16].

Efforts to optimize energy consumption and reduce the environmental impact of digital devices have been explored. Initiatives to decrease the energy consumption of digital devices have been proposed, including recommendations to lower consumption rates and mitigate the energy costs associated with digitalization (Arabi, 2023).

By conducting this study, the researchers aim to explore the properties of piezoelectric technology and hybrid energy, providing additional knowledge that can be utilized to improve the efficacy of energy consumption in the current digital age. The additional knowledge can be used to develop energy-saving techniques that will improve the energy consumption of digital technologies.

Developing self-powered keyboards using piezoelectric technology and hybrid energy sources would contribute to an environmentally friendly and technologically smart solution for usage. Every time keys are pressed, it generates small amounts of mechanical energy without power consumption. It also conserves energy because it is a lot more efficient than doing that every time anyone writes any words on their computer and hits the save button. Such a development could pave the way for plastic circuits and ultimately revolutionize how electricity is delivered to small household gadgets. It is expected to reduce the carbonization of global industrial processes and flights. In addition, this type of development could spur greater research development into renewable resource uses and help drive the market even further towards greener technologies across all sectors. The conversion from conventional to greener forms of power. It can save not only energy but also progress our technology.

This study is crucial because it addresses the growing concern about energy consumption by electronic devices, particularly computers. It aims to develop a self-powered keyboard design that harvests the mechanical energy of typing to generate electricity, thereby reducing reliance on external power sources and promoting sustainable innovation. This research could contribute to a more environmentally friendly and energy-efficient computing experience by exploring the potential of piezoelectric materials and hybrid energy harvesting techniques.

With the help of this project, consumers will be able to charge their devices using piezoelectric and hybrid energy harvesting techniques. Because of the keyboard's ability to convert typing energy to electrical energy, a section of it can operate on its own. Furthermore, this type of initiative benefits users in particular because it allows us to use our gadgets whenever we need them and eliminates the need for batteries. Our smartphones and other devices rely on energy, which is really beneficial because it allows us to utilize them for a variety of purposes while also keeping them connected.

The Digital Revolution and the broad use of digital technology, especially computers and the internet, have transformed almost every aspect of human life. Its importance to society has been impactful since technology has revolutionized communication, jobs, education, enjoyment, and even the perspectives of society's surroundings to the extent that it also influences the behavior of individuals (Fleur & Dlamini, 2022) [12]. Furthermore, along with the benefits that improve the quality of daily lives of people due to the digital age are the simultaneous integration of digital tools and technology that has made tasks easier, improved communication, and allowed information access, all of which contribute to raising the efficiency and effectiveness of both personal and professional spheres (Nzekwe-Excel, 2023) [20].

The increasing reliance on digital devices across various sectors, including education, work, and entertainment, underscores the urgent need for sustainable innovations in computer peripherals. For instance, this trend can be particularly pronounced in educational settings, where technology integration is becoming vital in improving teaching and learning approaches (Dangi *et al*., 2022) [9]. In addition, in the sector of entertainment, video games also experienced a significant increase in usage over the years resulting in increased usage in devices (Liang, 2022) [15]. Additionally, in the workplace, where computer use is prevalent, with employees typically spending between 6 to 8 hours per day on computers, with some workers spending up to 10 hours daily, has caused an increase in the usage of computers and devices (Chavhan & Gokhe, 2020) [7]. As a result of these activities that heavily rely on the usage of digital devices, computer usage has surged. Moreover, considering that the functionality of these devices is essential in the current state of society, computer usage will continue to increase. Hence, the development of a sustainable innovation in our digital technologies that are used daily is needed.

Furthermore, as computer usage continues to increase, so does energy consumption. Computers, among other ICT devices, account for a large portion of all the energy utilized (Basu *et al*., 2020) [6]. As more people adopt electronic devices into their daily lives, the sustainability of energy supply is also threatened. (Wen *et al*., 2021) [10].

The threats to energy supply sustainability present significant challenges that require urgent attention. Insufficient energy supply in various technologies can lead to significant detrimental effects across multiple sectors, including power systems, healthcare, and information technology. Energy poverty can arise from inadequate energy, particularly affecting vulnerable populations who may lack the means to secure sufficient electricity (Kazak *et al*., 2023) [13]. The lack of energy not only affects individual households but also has broader implications for community resilience and economic stability.

Along with the usage of computers, its peripherals is also being utilized. Specifically, keyboards. Keyboards are tools that are widely used to input data into computers and other devices featuring keys, for letters, numbers and commands making it a useful peripheral and plays a part in energy consumption.

One of the possible problems that may occur is battery depletion in wireless keyboards, which can seriously affect their usefulness and user productivity. Users using wireless keyboards could experience disruptions when the battery life is low or depleted since they depend on them for operation. This might cause annoyance by either sporadic connectivity problems or a total failure to recognize keystrokes, therefore upsetting workflow. Users could find themselves regularly needing to replace batteries or recharge them, which could be time-consuming and awkward. Furthermore, a declining battery level of a keyboard could compromise its responsiveness and functionality, therefore affecting either delayed replies or slower input registration. Particularly for jobs like data entry or coding that call for constant and effective typing, these interruptions might lower output. Users should routinely check battery levels, think about utilizing keyboards with longer-lasting batteries or rechargeable choices, and keep extra batteries on hand to guarantee continuous use in order to help to minimize these problems.

There has been attempts to address the increase of energy demand, and also discoveries of energy harvesters and converters. Specifically, Piezoelectric. This technology enables them to produce an electric charge in reaction to mechanical stress (Bajaba *et al*., 2022) [5]; remarkable chemicals known as piezoelectric materials, when pressed, may generate an electric charge. This unique capability is extremely helpful in a variety of applications, such as sensors, actuators, and energy harvesting devices. Moreover, hybrid energy systems, which combine solar and piezoelectric enable to harvest of more energy in gadgets. Using hybrid energy can add components to lower costs, lessen system interruptions, and lessen their impact on the environment.

There have been integrations of piezoelectric materials on a mechanical keyboard with the purpose of a self-powered computer using a piezoelectric material-powered keyboard, but the results showed that the energy produced by the piezoelectric materials is not enough to power up a computer. However, insufficient knowledge regarding the integration of piezoelectric materials and hybrid energy harvesters in keyboards has yet to be fully explored (Nandpure & Kelkar, 2023) [19].

Ultimately, while there has been research on piezoelectric materials and energy harvesting, there is limited exploration of their integration into keyboard designs and their impact on user typing behavior. Existing studies do not address how different designs of hybrid energy systems influence energy harvesting efficiency and user experience.

Combining active sensors with piezoelectric technology, this applies mechanical stress to produce an electrical charge that can be used immediately by small electronic devices or sensors, improving energy efficiency and weaning ourselves off the grid, so there may be less reliance upon wide-ranging types of electricity generation for individuals' day-to-day lives. In contrast, hybrid energy combines multiple forms of energy, such as solar power, wind-generated electrical energy, and fossil fuels tied into a super-efficient power system. In various systems, the marriage of piezoelectric and hybrid energy could improve reliability and efficiency. For example, piezoelectric devices under highways might capture energy from traffic vibrations. This energy could then be stored and distributed by conventional means to run street lights or other infrastructure. Simultaneously, a hybrid energy system would be able to deliver a continuous and environmentally friendly power supply, which would make for more sustainable and robust management of energy. Together, this would represent a huge step forward in conserving energy, cutting our carbon footprint, and improving overall living conditions.

With the help of this initiative, users will be able to charge their gadgets through the use of piezoelectric and hybrid energy harvesting techniques. A portion can run on its own power due to the keyboard's ability to transfer the energy from typing to electrical energy. Additionally, this type of project is beneficial to users in particular, as it allows us to use our devices whenever we need to and eliminates the need for batteries. Our smartphones and other devices run on energy, which is quite useful because it lets us use them for a lot of different things and keep them connected.

Despite advancements in energy harvesting technologies, such as piezoelectric and hybrid energy systems, there is a lack of efficient and practical applications for these technologies in consumer keyboards. The current keyboards do not fully leverage these technologies to reduce dependency on external power sources, leading to inefficiencies and higher environmental costs.

Objectives of the Study

This study aims to develop and explore a self-powered keyboard design that harvests the mechanical energy of typing to generate electricity, thereby reducing reliance on external power sources and promoting sustainable innovation. This research aims to contribute knowledge in developing a more environmentally friendly and energy-efficient computing experience by exploring the potential of piezoelectric materials and hybrid energy harvesting techniques. Specifically, this study aims to (1) determine the components that were utilized to create Self-Powered Keyboards; (2) identify the procedure for the integration of harvesting techniques, such as solar panels, with piezoelectric technology to increase the keyboard's power generation capacity; (3) distinguish how users' typing behavior affect harvesting energy in terms of keystroke frequency, duration, and force; (4) identify how keyboards with integrated energy harvesters impact users' quality of usage.

Methods and Materials

This study uses a quasi-experimental research design. A quasi-experimental study design is a systematic strategy for modifying one or more independent variables to assess their effect on a dependent variable while controlling for extraneous effects (Collom, 2021) [8]. Furthermore, in studies where randomization is not feasible, quasi-experimental designs are a basic methodological technique. These methods let researchers find causal relationships between variables even when they admit the restrictions of not being able to control all extraneous factors. Emphasizing their relevance in situations when traditional experimental designs are impractical. (Akbar *et al*., 2022) [1].

Table 1: Solar Panel Specification

Maximum Power (Pmax)	3W
Voltage at Pmax (Vmp)	6V
Current at Pmax (Imp)	0.5A
Open Circuit Voltage (Voc)	7.2V
Short Circuit Current (Lsc)	0.55A
Power Tolerance	+/-3%
Measurement	233*140*15MM

Table 1 presents the specifications of a solar panel selected to enhance the energy harvesting capabilities of a piezoelectric keyboard system. This will be the only solar panel that will be utilized for the research due to its availability in the market for the researchers.

Furthermore, the researchers placed the piezoelectric sensors on specific keys to simulate the different average typing speeds of different typers. This is because the average words per minute (WPM) for different typers can vary significantly based on several factors, including the typist's experience, the context of typing (e.g., casual vs. professional), and the medium (e.g., keyboard vs. touchscreen). Research indicates that the average typing speed for proficient typists typically ranges from 40 to 75 WPM, while expert typists can achieve speeds exceeding 100 WPM (Graham & Ginkel, 2014; Chiang & Griego, 2017).

Additionally, the letter keys such as 'E', 'T', 'A', 'O', 'I', and 'N' are among the most pressed due to their high frequency in the English language. Studies have shown that these letters constitute a significant portion of written text, leading to their frequent use in typing Faria & Kim (2015).

Moreover, space bars, enter keys, and backspace keys are heavily utilized as they are essential for spacing, executing commands, and correcting mistakes, respectively (Kern *et al*., 2023). The shift keys are also frequently pressed, particularly in combination with other keys to produce uppercase letters and special characters (Kern *et al*., 2023).

Moreover, the keyboard that will be selected for this study based on investigating the impact of keyboard designs in efficient energy harvesting is a mechanical keyboard that is Tenkeyless (TKL) or keyboards without a number pad. Tenkeyless (TKL) keyboards typically have 87 or 88 keys. Which is about 80% of the full-sized keyboard layout. Hence, often referred to as 80% keyboards. Specifically, this study will investigate the impact of key shape, material, and layout of a RK87 keyboard with Cherry MX Red Switches on the efficiency of energy harvesting. Furthermore, this research will be limited to the design of a Tenkeyless (TKL) keyboard. Specifically, RK87 with Cherry MX Red Switches. It will not explore every possible variation of keyboard design, due to time constraints, and budget constraints of the researchers.

To evaluate the viability of incorporating piezoelectric technologies and hybrid energy systems into keyboard design. This strategy focuses on measuring certain factors, such as keystroke energy output, in order to derive empirical conclusions regarding the proposed technology's performance.

This study aims to choose appropriate piezoelectric materials and create testable keyboard prototypes that run on their own energy. The energy extracted from mechanical operations will be quantified. The data will next undergo statistical analysis to compare the performance of the self-powered keyboards to conventional versions. A working prototype proving the practicality of piezoelectric technology is one of the expected results, and empirical data on user performance will give a thorough grasp of the technology's potential for long-term advancement.

The population selected includes people who are interested in innovative and sustainable technology. This population therefore encompasses the target group in which we wish to implement our research. This study group would be made up of people who regularly use keyboards such as office employees or students who are also gamers in their time and individuals intrigued by new and environmentally friendly technology; essentially representing the audience we aim to engage with through our research project. The participants for the user typing behavior experiments will be limited to a specific demographic, and will only have 5 participants and will only be the researchers and one professional science teacher.

The user typing behavior experiments will be conducted in the researcher's home, located in Noveleta, Cavite, and will not include other municipalities outside Noveleta to create an efficient budget system that aligns appropriately for the researchers and to reduce the effects of time constraints.

Furthermore, this study regarding self-powered keyboards aims to contribute additional knowledge to formulating practical strategies and sustainable innovation that will reduce the adverse effects of increased energy consumption as a result of increased usage of technological devices. The researchers will focus on the development and evaluation of self-powered keyboards utilizing piezoelectric technology and hybrid energy systems. The hybrid energy system specifically will contain only piezoelectric and solar technology to harvest energy. It will not cover other energy harvesting technologies outside these two areas. The primary measurement will be the amount of energy harvested during typing. This researcher will quantify energy in terms of electrical output generated by piezoelectric and hybrid systems. Furthermore, the study will examine how various different typing behaviors of typing in speed, force, and pattern and how it influences the amount of energy harvested. This will involve controlled experimental conditions to simulate different typing behaviors.

This quasi-experimental research aims to answer specific questions related to energy harvester components, integration techniques, and user typing behavior. The researchers employed multiple analysis methods to attain the objectives. Descriptive statistics were utilized to allow researchers to present complex data insights effectively. This is achieved through numerous approaches, with measurements of means, medians, standard deviations, and ranges for key metrics such as voltage and current produced per keystroke, as well as typing behavior metrics (keystroke frequency, duration, and force) (Alabi, 2023; Mishra *et al*., 2019) [2, 18]. Descriptive statistics simplify challenging data, facilitating effective result communication, and they provide the basis for more sophisticated statistical studies (Srivastava, 2024) [23].

However, interpretation of results could be better if researchers over-rely on summary statistics without considering the backdrop or the probable biases in the data collection process (Rama *et al*., 2023; Dindorf *et al*., 2020) [22, 3]. Therefore, they should be complemented with inferential techniques to draw stronger conclusions and to guarantee the validity of the research findings (Korošec & Eftowicz, 2020; Priyougie *et al*., 2022) [14, 21].

Results and Discussion

Table 2: Measuring Piezoelectric Energy

Trial	Time Spent Typing	Force	Average Voltage (V) per Key Press	Average Current (mA) per Key Press	Rank
1	10 seconds	Light Presses	0.098	0.0023	8
2	10 seconds	Heavy Presses	0.157	0.0047	4
3	10 seconds	Repeated Light Presses	0.527	0.0017	3
4	10 seconds	Repeated Heavy Presses	0.479	0.0089	2
5	15 seconds	Light Presses	0.120	0.0014	7
6	15 seconds	Heavy Presses	0.201	0.0018	6
7	15 seconds	Repeated Light Presses	0.379	0.0012	5
8	15 seconds	Repeated Heavy Presses	0.543	0.0076	1

Trials were conducted over a consistent 10-second and 15-second duration to allow for comparability along with different types of force. The trials assessed light and heavy key presses, both individually and as repeated actions, to illustrate how the different typing behaviors affect the energy output of a piezoelectric keyboard system.
As shown in Table 2, the voltage values are more spread out statistically than the current values. This could be because the force is being applied to the key at a different angle, the pressure is different, or the key is not touching the piezo in the same area. All of these things can change the voltage but not the current very much.
Furthermore, the data shows that the amount of energy collected is affected by both how hard (intensity) you type and how often you type. Most of the time, heavy presses make more voltage and current than small presses. However, doing the same thing over and over again greatly increases voltage, which suggests that typing quickly can effectively improve energy harvesting efficiency. This table consistently shows that heavy and repeated presses provide the most energy.
Moreover, it is worth noting that the design or placement of the Piezoelectric material also influences how much energy is produced. The optimal placement of the sensor requires a design where the user's force fully affects the sensor. Because as it is shown in the table, in some trials, it was shown that the piezoelectric integration onto the keycaps of the keyboard also played a factor in how much energy is being harvested.
Additionally, user Typing Behavior plays a critical role. Fast, forceful typing maximizes piezoelectric output. Incorporating sensors that adapt to different typing styles could optimize energy harvesting.

Table 3: Solar Panel Energy Measurement

Trial	Light Intensity	Average Voltage (V)	Average Current (A)	Power (W)
1	Close to Indoor Lighting	5.8 V	0.28A	1.624W
2	Moderately Far from Indoor Lighting	5.6V	0.26A	1.456W
3	Very near to Indoor Lighting	6.0V	0.30A	1.800W

The results from the three trials illustrate the impact of varying light intensity on the energy output of the solar panel under indoor lighting conditions. As expected, the power generated by the panel fluctuates depending on the light levels in the room, which is a key factor influencing the performance of the panel. The results reinforce that solar panels perform best under direct sunlight, and energy production under indoor light is much lower. Overall, the panel's power output fluctuates, with maximum power being much lower than its rated 3W due to the indoor lighting conditions.
As shown in the table, power output increases with proximity to a light source. Trial 3 (Very Near to Lighting) achieved the highest power output of 1.8W, compared to 1.456W and 1.624W in moderately lit and distant positions, respectively. But, even in less optimal conditions (Trial 2), the panels still generated a usable power output. Suggesting that even without the highest power output achieved by the solar panel, if combined with another energy harvester can still produce a considerable amount of energy that can be stored and used.
Furthermore, by combining piezoelectric and solar energy harvesting a continuous power supply can be created. With Solar panels supplying baseline power during the day or in well-lit environments and Piezoelectric harvesting can complement this by generating energy from user activity, ensuring power supply in darker environments or at night. By combining these two energy harvesters it leverages both active user interactions and passive ambient energy.

Conclusion

The combination of the two systems makes charging small electronic devices feasible. The solar panel component provides most of the energy in charging, and Piezoelectric energy design, with the user's typing behaviors, acts as a supplementary source but is not a primary contributor. With proper energy storage and usage optimization, the self-powered keyboard can sustainably meet its energy needs. It can also charge some low-power devices, such as other wireless keyboards, mice, and Bluetooth devices.
Moreover, this hybrid energy system is specifically useful for students, office workers, and gamers. As students increasingly rely on technology for their education, keyboards that harvest energy from keystrokes can provide a continuous power supply for devices, reducing interruptions during study sessions. Gamers and office workers, who often spend extended periods engaged with their devices, can convert keystrokes into usable energy, which can enhance the gaming and working experience by ensuring that devices remain charged without the need for frequent breaks to recharge. Additionally, this can be used as a backup power for emergency situations where access to conventional power sources is limited.

Recommendations

The researchers recommend several strategies to optimize the performance and usability of the self-powered keyboard. First, energy harvesting can be enhanced by using advanced materials such as high-performance piezoelectric components (e.g., PZT or PVDF) and efficient solar cells like monocrystalline panels. Exploring the different designs of keyboard mechanisms to amplify mechanical force on piezoelectric elements and strategically positioning solar panels for maximum light exposure will further improve energy output. Second, integrating efficient energy storage solutions, such as rechargeable batteries or capacitors, alongside smart power management circuits, will ensure consistent energy availability and stabilize power delivery. Third, user typing behavior can play a significant role in energy generation; encouraging deliberate, consistent typing patterns and gamifying the process through visual feedback systems can maximize output while engaging users. These improvements, coupled with user-friendly designs and sustainable materials, will create an improved version of an innovative, eco-friendly keyboard capable of reliably powering low-energy devices and operating independently for extended periods.

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