Biomechanic-Based Design of Knee Protector Generator for Portable Electricity Generation to Support Military Operations in the Field

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Abstract-
Background: In the 5.0 era which depends on electrical energy, innovation is needed to overcome the limitations of batteries in electronic devices. An innovative device has been created that uses knee joint movement to produce renewable energy.
Objective: Knee movements are converted into electrical energy through a special gearbox that rotates a generator, converting the energy to a power bank as a storage medium.
Methods: This study used an experimental method.
Result: This research produces 5.6 Watts of power, providing an effective solution for charging batteries in mobility conditions.
Conclusion: By utilizing knee joint movements and biomechanical analysis, this tool can utilize differences in force, angle and speed of movement to produce the required electricity.

Keywords: Biomechanic, Charging, Generator, Gearbox, Portable

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1. INTRODUCTION

Along with the times and technology, energy is an inseparable element of human life because every work done requires and produces energy. In various energy sources, there are activities of the human body that have the potential to produce energy that can be utilised [1], one of the uses of energy is the use of electrical energy in electronic devices. Most of the utilisation of energy sources still comes from non-renewable materials using carbon-based and fossil fuels so that it continues to have an impact on the environment and the availability of materials [2]. With these problems, there is a need for solutions and innovations in the utilisation of renewable and environmentally friendly energy, and for now various kinds of research are being developed on the utilisation of energy sources derived from solar, wind, water, and other energy [3].

According to the Indonesia Clean Energy Status Report 2023, Indonesia is rich in renewable energy potential including solar, hydro, wind, biomass, marine, and geothermal energy that has not been optimally utilised. According to ESDM data, with current technology, the potential for electricity from renewable energy reaches 432 GW, or 7-8 times the current total installed generating capacity [4]. The electrical energy sector is not only needed in industry, transportation, and health but also in military and defence. Weapons are a key element in maintaining the country's sovereignty. Military technology tools assist TNI members in performing their duties effectively while reducing risks to personnel and material assets. Most of TNI's military equipment today uses electronics-based technology such as Handy Talkie (HT), radio, GPS, and robotics devices. To run this equipment, electricity is the main requirement [5].

With the conditions faced by soldiers when carrying out assignments in border areas of Indonesia that are difficult to reach by the availability of electricity, it is a problem that needs to be considered as well as the limited supply of power in the battery in electronic devices by requiring a charging process that still uses AC (Alternating Current) electric current [6] and an adapter is needed which is useful for adjusting the voltage and current requirements on the battery. In this case, the battery charging process is still sedentary, while the task of TNI soldiers is required to be mobile in every movement, so a portable and wearable device is needed [7].

Similar research in 2019, conducted by Jun Fan [8] and his team on lightweight biomechanical energy harvesters with high power density and low metabolic costs with experimental results showing that cable pulley harvesters produce an average of 4.1 Watts of electricity with the lightest mass and highest power density, and the user's metabolic power growth rate is still low. Then further research in 2019 conducted by Long Han Xie [9] and his team regarding the prototype of the harvester machine was made to test its performance. The experimental results show that at a walking speed of 4.2 km/h, the energy harvester can reduce the metabolic cost of walking by 3.6%, with a spring stiffness of 2 Nm/rad and an electrical damping coefficient of 0.5, and an average voltage. 2.4W power is generated in the harvesting process. Further research was conducted by Ahmad Khan [2] and his team on biomechanical knee energy harvesters with the result that the voltage capable of being produced during the experiment varied between 4.5 V to 6.5V, depending proportionally on the angular velocity and inversely proportional to the duration of the knee gait where a higher angular velocity will produce a higher voltage, but with a longer gait duration, the generation efficiency decreases. When faced with military activities or activities, a tool that is able to efficiently and withstand all obstacles is needed, so **the novelty of this research** is an innovative biomechanics-based knee protection generator design for portable electrical energy generation to support military operations in the field..

The purpose of this research is to create a tool that functions as Smart Charging [5] is an innovation in efforts to utilise renewable and environmentally friendly energy so that it can be used in daily life activities. This tool can work through the utilisation of mechanical energy derived from human body movements then converted into electrical energy [10] so that it can be used to carry out the charging process on electronic device batteries [11].

2. METHODS

2.1. Research Flowchart

The research method carried out by researchers can be shown in Figure 1.

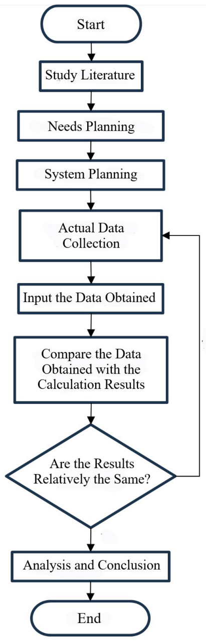

Figure 1. Flowchart of Research Phase

Based on Figure 1, the stages of this research begin with a literature study that will look for references from research journals, conference articles or proceedings to books on energy conversion techniques, by utilising mechanical energy from human body movements that can be converted into electrical energy. After planning the needs of the tool, the next stage can be done system design which includes designing the system to the implementation of the tool. Then data collection is carried out from the tool that has been made to be evaluated. The results of the data collection will be analysed to determine the performance of the proposed tool.

2.2. Biomechanics

Biomechanics is a branch of science that studies the mechanics of movement and structure of biological systems, particularly the bodies of humans, animals, and other living organisms. It includes the study of how force, motion, and other physical mechanisms affect and are affected by biological structures as well as how organisms use mechanics to move, adapt, and function within their environment. In medicine, sports, engineering, and other sciences, knowledge in biomechanics is often used to understand the way the body moves, muscle-bone injuries, the design of medical equipment, and the development of technologies that can assist in rehabilitation and physical performance [12]. In this research, a system capable of generating electricity through biomechanical energy harvesting was created, with the energy input coming from the mechanical movement of human joints [13]. The main objective is to reduce the user's dependence on backup batteries. The research involved the design of a harvester that uses pulleys and lightweight cables that are attached to the knee joint [8].

2.3. Energy Conversion Mechanism

Different types of energy conversion mechanisms can be used to convert kinetic power from the human body into electric power, such as electromagnetic, piezoelectric, electrostatic, and triboelectric energy converters, etc. All electromagnetic, electrostatic, and riboelectric conversions are motion-based and suitable for situations where the speed or amplitude of excitation is large[10]. Due to its adaptability to the environment, mechanical energy stands out among various energy sources. However, mechanical energy is often neglected and wasted in daily life. The human body, as one of the main energy sources, has a significant potential of biomechanical energy in low frequency (1-5Hz), which is generated through joint movements, breathing, and heartbeat. This energy never stops as long as humans move [14].

2.3.1. Knee Joint Movements

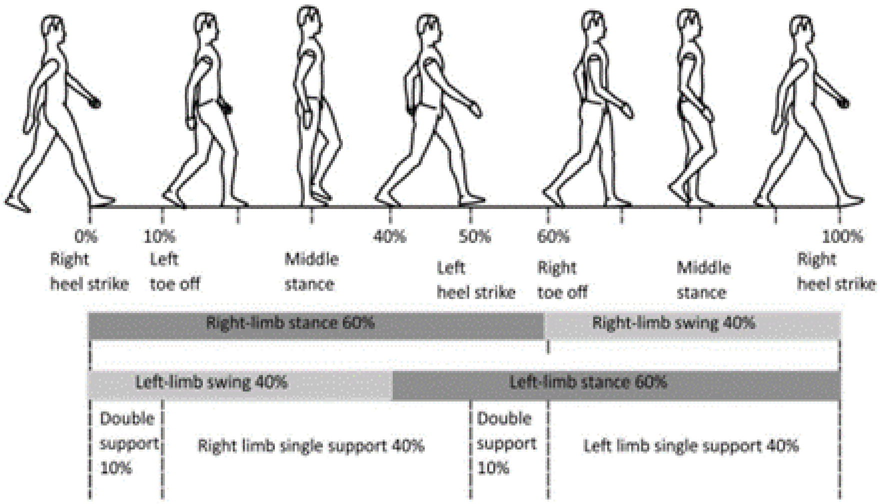

Figure 2. Human walking cycle

Kinetic energy in the human body comes in many forms, but it is not evenly distributed. During the walking condition, there is a large amount of kinetic energy gathered at the knee joint, which is used to speed up and slow down the movement of the lower limbs. The quadriceps (femoris) and hamstrings muscles help rotate the knee joint. These two muscle groups can be simplified into a single muscle with similar mechanics, connected to the calf via tendons, giving the leg a leveraging effect [9].

The biomechanical properties of muscles allow further simplification into function models that describe muscles as springs and dampers. The elasticity properties of a spring-like muscle allow it to store kinetic energy when stretched, which is then released to accelerate lower limb movement. The damper in this model acts as a component that absorbs energy when muscle force is generated.

The human walking cycle diagram shows the process from heel strike to the next heel strike on the same foot. Double support, about 10% of the walking cycle, is the period between the initial contact of the right foot and the left foot leaving the ground. Subsequently, the right leg supports the body, providing a period of single support that contributes about 40% of the walking cycle [9].

Table 1. Walking speed and Angle

Walking Speed (Km/hr)	Walking Angle (degrees)
< 1	0-10
1 - 3	10-20
3 - 5	20-30
5 - 7	30-40
> 7	> 40

2.3.2. Electromagnetic Effect

Faraday's Law of Electromagnetic Induction [10] states that electromotive force will be induced in a conductor located in a changing magnetic field as seen in Figure 4. The mathematical formula for Faraday's law can be expressed as follows:

$$\varepsilon = \frac{d\phi}{dt} \tag{1}$$

where:

ε = Potential difference (voltage) generated in the conductor (volts).

$\frac{d\phi}{dt}$ = Change in magnetic flux in a given time (w/s).

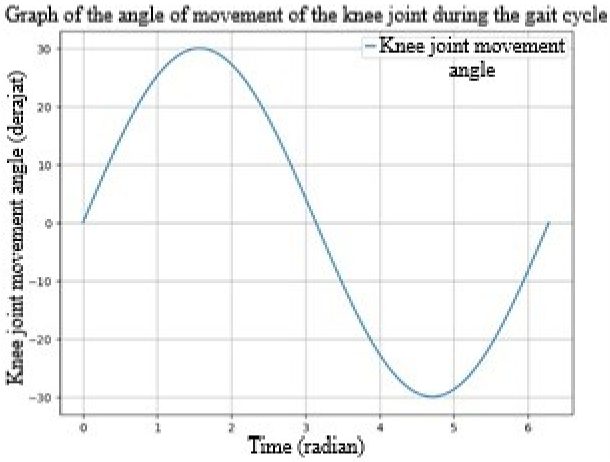

Figure 3. Knee Joint movement chart

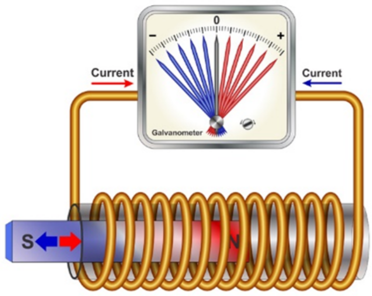

Figure 4. Electromagnetic Transducer

The magnetic flux (Φ) through a given region can be calculated by the formula:

$$\Phi = B, A, cos\theta \quad (2)$$

where:

B = Magnetic induction (tesla).
A = The surface area travelled by the magnetic field (m^2).
θ = The angle between the magnetic induction vector and the vector normal to the surface (°).

2.3.3. Harvester

Energy harvesters are designed to assist human walking without changing the wearer's original walking pattern thus careful selection of energy harvester parameters is required. The analysis presented is based on the assumption that the energy harvester will not change the wearer's walking pattern [9]. Through electromechanical transducers converting mechanical energy into electrical energy, in the form of AC (alternating current) [15] thus requiring a process of rectification as well as adjustment of the electronic circuit shown in Figure 5.

3. RESULTS AND DISCUSSION

3.1. Tool Design

Through design and drafting will consider the use of biomechanical technology and engineering principles to develop a strong and lightweight structure. This innovative approach will enable efficient utilisation of knee movements, turning them into a reliable source of energy for charging portable military equipment. In addition, the design focus will be given to the aspects of portability, durability, and ease of use so that this generator can effectively meet the operational needs of the field with the design and design of the device shown in Figure 6.

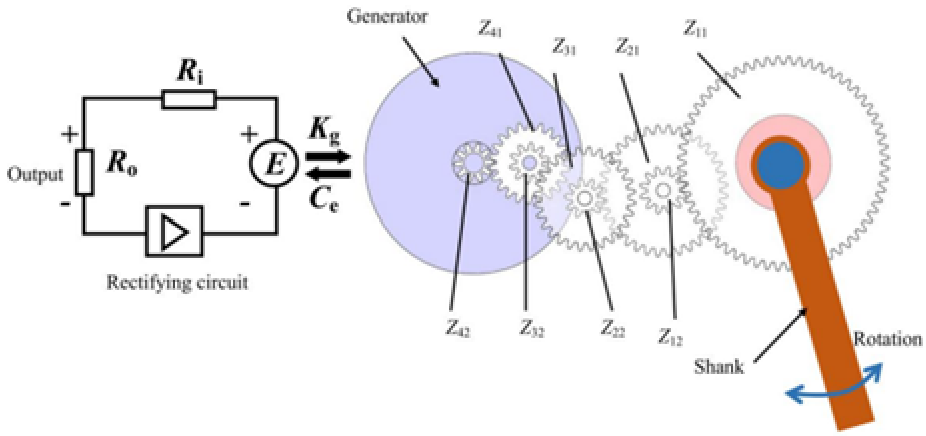

Figure 5. Schematic Diagram of Transmission on Energy Harvester

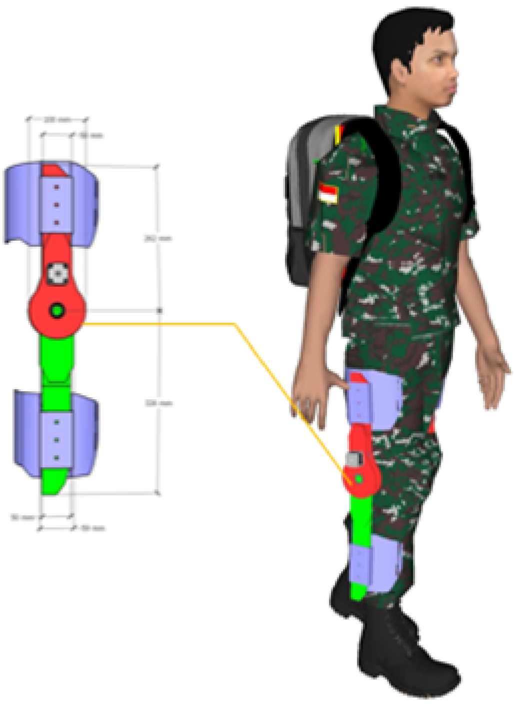

Figure 6. Tool Design

3.2. Generator Testing

The generator testing process will involve a series of rigorous trials to evaluate the device's performance and durability under a range of possible field conditions, including simulated use on harsh terrain and variations in knee movement intensity. This testing will help identify the generator's potential and limitations, and ensure that the device can provide reliable and consistent electrical power during military operations in the field.

3.2.1. Voltage

The generator testing process will involve a series of rigorous trials to evaluate the performance and durability of the device under a wide range of possible field conditions [16], including simulated use on harsh terrain and variations in the intensity of knee movements. This testing will help identify the generator's potential and limitations, and ensure that the device can provide reliable and consistent electrical power during military operations in the field. Through the linear regression equation for output voltage (V) against rotation speed (rpm) it can be written as follows:

$$V = a \times rpm + b \quad (3)$$

where:
V = Output voltage
a = Regression coefficients calculated using the linear regression method from experimental data.
RPM = Rotation revolutions per minute
b = Regression coefficient the regression coefficient is calculated using the linear regression method from experimental data
With the output voltage results shown in Table 2 and Figure 7.

Table 2. Voltage testing

Velocity (rpm)	Output voltage (V)
50	5
60	6
70	7
80	7,5
90	8

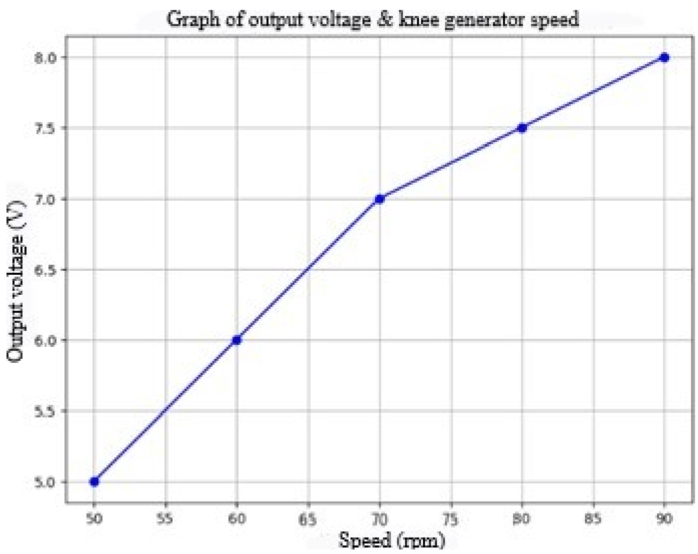

Figure 7. Output Voltage Graph

3.2.2. Current

Through the linear regression equation for output current (A) against rotation speed (rpm) the following formula can be written:

$$A = c \times rpm + d \quad (4)$$

where:
A = Output current
c = Regression coefficients calculated from experimental data
rpm = Rotation revolutions per minute
d = Regression coefficients calculated from experimental data
By testing the resulting current, this research aims to gain a deeper understanding of the characteristics of the current flowing through the electronic system or device being evaluated as shown in Table 3 and Figure 8.

Table 3. Current Testing

Velocity (rpm)	Output Current (A)
50	0,3
60	0,4
70	0,5
80	0,6
90	0,7

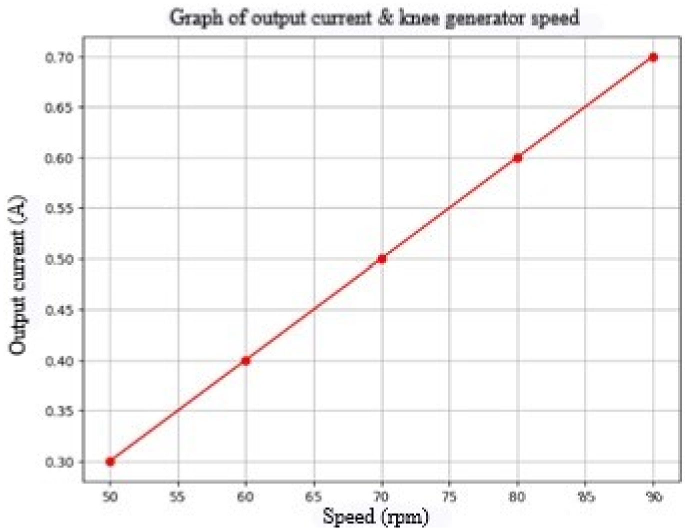

Figure 8. Grafik Arus Keluaran

3.2.3. Power

Using the linear regression equation, output power (W) versus rotation speed (rpm) can be written in the following formula:

$$W = e \times rpm + f \quad (5)$$

where:

W = Output voltage

e = Regression coefficients calculated from experimental data

rpm = Rotation revolutions per minute

f = Regression coefficients calculated from experimental data

The results of this testing will provide important insights in evaluating the performance of a system or device in producing power according to needs, determining whether the device is operating at maximum efficiency, and ensuring that the power produced meets established safety and performance standards [17] as shown in Table 4 and Figure 9.

Table 4. Power testing

Velocity (rpm)	Power (W)
50	1,5
60	2,4
70	3,5
80	4,5
90	5,6

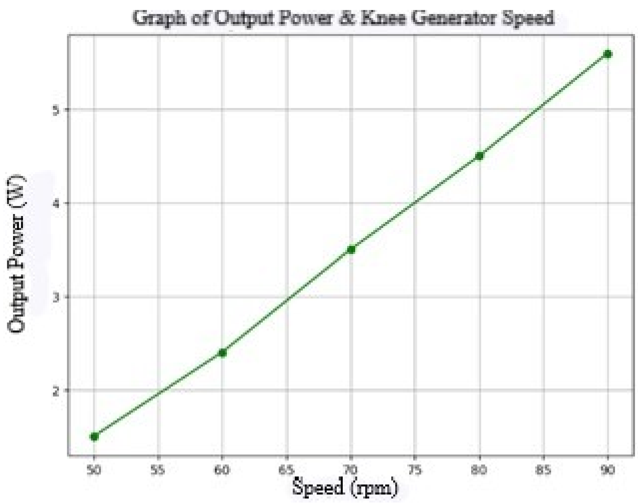

Figure 9. Output power graph

Based on the results of the tests that have been carried out that the constituent components for making technology that converts physical movements, especially knee joint movements when walking or running, into electrical energy have been successfully tested. Testing of this tool shows that the movement of the knee joint with different angles, power and speed can produce a voltage of up to 8 Volts and a current of 0.7 Amperes, producing power reaching 5.6 Watts when operating at a speed of 90 Rpm. **This research confirms the research that has been done by previous researchers** [2][8].

4. CONCLUSION

Technology that converts physical movement, especially knee joint movement when walking or running, into electrical energy has great potential for charging portable and wearable military electronic devices. Testing of this tool shows that movement of the knee joint with different angles, power and speed can produce a voltage of up to 8 Volts and a current of 0.7 Ampere, producing power reaching 5.6 Watts when operating at a speed of 90 Rpm. With the power produced, this tool can be used to charge military electronic devices according to needs when in the field or on assignment. Implementation of this technology faces several challenges that need to be overcome. The efficiency, consistency and stability of electrical energy production from knee joint movements are critical aspects that need to be considered. The design of the tool must also be ergonomic, not hamper the user's mobility, and be able to withstand the harsh environmental conditions in the military field of duty. Additionally, it is important to ensure the safety of charged electronic devices, maintain data integrity, and ensure compatibility and ease of integration of this technology with a variety of military electronic devices. There is also a need for training for military personnel on the use, care and maintenance of these tools to ensure their effective and efficient use in the long term. Although promising, further development and comprehensive trials are needed before this technology can be widely adopted on a military operational scale.

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REFERENCES

[1] A. A. Lostari and R. Y. Hartono, "Desain Ransel Penghasil Listrik dengan Memanfaatkan Tenaga Gerak Berjalan Manusia," *MULTITEK INDONESIA*, vol. 13, no. 2, pp. 128–134, dec 2019. [Online]. Available: https://journal.umpo.ac.id/index.php/multitek/article/view/2029

[2] A. Khan, O. Allawi, S. Parasuraman, G. Kosalishkwaran, T. Chung, W. H. Lim, and C. K. Ang, "Biomechanical Knee Energy Harvester," in *2020 International Conference on Advanced Materials, Information Systems and Mechanical Engineering (AMISM 2020).* 2020 International Conference on Advanced Materials, Information Systems and Mechanical Engineering (AMISM 2020), dec 2020.

[3] H. Fu, X. Mei, D. Yurchenko, S. Zhou, S. Theodossiades, K. Nakano, and E. M. Yeatman, "Rotational energy harvesting for self-powered sensing," *Joule*, vol. 5, no. 5, pp. 1074–1118, may 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S254243512100101X

[4] A. P. Tampubolon and J. C. Adiatma, "Laporan Status Energi Terbarukan Indonesia," IESR, Tech. Rep., 2019. [Online]. Available: https://iesr.or.id/infografis/laporan-status-energi-terbarukan-indonesia

[5] M. Suprayadi, K. Suryadi, and D. Widiatmoko, "Smart Charging with Stepper pada Sepatu PDL TNI sebagai Supply Alat Komunikasi Saat Patroli di Daerah Perbatasan," *Jurnal Elkasista*, vol. 1, pp. 1–6, may 2020. [Online]. Available: https://journal.poltekad.ac.id/index.php/elka/article/view/68

[6] N. Prastantyo, *Rancang Bangun Regulator Capasitor Bank Menggunakan Metode Fast Charge Untuk Sepatu.* Batu: Poltekad Kodiklatad, 2022.

[7] Y.-W. Chong, W. Ismail, K. Ko, and C.-Y. Lee, "Energy Harvesting For Wearable Devices: A Review," *IEEE Sensors Journal*, vol. 19, no. 20, pp. 9047–9062, oct 2019. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/8750873

[8] J. Fan, C.-H. Xiong, Z.-K. Huang, C.-B. Wang, and W.-B. Chen, "A lightweight biomechanical energy harvester with high power density and low metabolic cost," *Energy Conversion and Management*, vol. 195, pp. 641–649, sep 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0196890419305734

[9] L. Xie, X. Li, S. Cai, G. Huang, and L. Huang, "Knee-braced energy harvester: Reclaim energy and assist walking," *Mechanical Systems and Signal Processing*, vol. 127, pp. 172–189, jul 2019.

[10] Y. Yun, S. Jang, S. Cho, S. H. Lee, H. J. Hwang, and D. Choi, "Exo-shoe triboelectric nanogenerator: Toward high-performance wearable biomechanical energy harvester," *Nano Energy*, vol. 80, p. 105525, feb 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2211285520310995

[11] M. Liu, F. Qian, J. Mi, and L. Zuo, "Biomechanical energy harvesting for wearable and mobile devices: State-of-the-art and future directions," *Applied Energy*, vol. 321, p. 119379, sep 2022.

[12] L. Zhang, G. Liu, B. Han, Z. Wang, Y. Yan, J. Ma, and P. Wei, "Knee Joint Biomechanics in Physiological Conditions and How Pathologies Can Affect It: A Systematic Review," *Applied Bionics and Biomechanics*, vol. 2020, p. 7451683, apr 2020. [Online]. Available: https://doi.org/10.1155/2020/7451683

[13] M. Gad, B. Lev-Ari, A. Shapiro, C. Ben-David, and R. Riemer, "Biomechanical knee energy harvester: Design optimization and testing," *Frontiers in Robotics and AI*, vol. 9, p. 998248, oct 2022. [Online]. Available: https://www.frontiersin.org/articles/10.3389/frobt.2022.998248

[14] L. Niu, X. Miao, G. Jiang, A. Wan, Y. Li, and Q. Liu, "Biomechanical energy harvest based on textiles used in self-powering clothing," *Journal of Engineered Fibers and Fabrics*, vol. 15, p. 1558925020967352, jan 2020. [Online]. Available: https://doi.org/10.1177/1558925020967352

[15] J. Liang, L. Xin, and Y. Hailiang, "Kinetic Energy Harvesting Toward Battery-Free IoT: Fundamentals, Co-Design Necessity and Prospects," *ZTE Communications*, vol. 19, no. 1, pp. 48–60, 2021. [Online]. Available: https://kns.cnki.net/kcms/detail/34.1294.

[16] M. Junaldy, S. R. U. A. Sompie, and L. S. Patras, "Rancang Bangun Alat Pemantau Arus Dan Tegangan Di Sistem Panel Surya Berbasis Arduino Uno," *Jurnal Teknik Elektro dan Komputer*, vol. 8, no. 1, pp. 9–14, apr 2019. [Online]. Available: https://ejournal.unsrat.ac.id/v3/index.php/elekdankom/article/view/23647

[17] I. D. Christanto, R. Diharja, M. Mardiono, P. D. Widayaka, and A. H. Yuwono, "Mirroring Display KWH Meter untuk Memantau Penggunaan Daya Listrik Menggunakan Mikrokontroler ESP32-CAM," *Jurnal Bumigora Information Technology (BITe)*, vol. 3, no. 2, pp. 161–174, 2021. [Online]. Available: https://journal.universitasbumigora.ac.id/index.php/bite/article/view/1613

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